THE WAR YEARS (1917–19)

CHAPTER IV

THE BUREAU TURNS TO WAR RESEARCH

The war began in faraway Europe on August 4, 1914 and for several months the stock market and the American public were profoundly depressed. Then the long battle line across northern France stabilized, rifle pits became trenches, and as winter approached it appeared that the war had come to stay. Its early threat to American security was countered by President Wilson's declaration of neutrality; its threat to our economic stability dissipated as America became the arsenal of the Allies, supplying them with money, credits, munitions, oil, chemicals, explosives, and foodstuffs.[1]

Pursuing neutrality, no Government agency made the slightest attempt to interfere in the booming production of war materials until a congressional act of August 1916, looking to a "future war of defense inferentially far distant," set up the Council of National Defense. Composed of the Secretaries of War, Navy, Interior, Agriculture, Commerce, and Labor, it was to make recommendations to the President "for the co-ordination of industries and resources for the national security and welfare." [2] Under no pressure and without a directive, the Council marked time until after war was declared, when its principal function was effectively assumed by the all-powerful War Industries Board, under Bernard Baruch.

The first actual war-research agency of World War I was the National Advisory Committee for Aeronautics (NACA), established by Congress in March 1915 to initiate and direct scientific studies in problems of flight. The Bureau of Standards, represented on the Committee by Dr. Stratton, was asked to begin investigations at once of the physical factors in aeronautic

[1] Exclusive of neutral countries, exports to the Allies rose from $927 million in 1914 to $3,013 million in 1916. Arthur C. Bining, The Rise of American Economic Life (New York: Charles Scribner's, 1943), p. 564; William E. Leuchtenburg, The Perils of Prosperity, 1914–1932 (University of Chicago Press, 1958), p. 16.

[2] First Annual Report, Council of National Defense, 1917–18, p. 6; Second Annual Report, 1918–19, p. 5.

design.[3] Many of the aviation problems subsequently assigned by NACA to the Navy and War Departments were, since they lacked research facilities, turned over to the Bureau as it "became the scientific laboratory for the two military services." [4]

The initial attempt to mobilize the scientific and technical resources of the Nation began in the Naval Consulting Board, appointed by Secretary of the Navy Daniels in mid-1915. Headed by Thomas Edison, then in his 68th year, with Willis R. Whitney, Frank J. Sprague, L. H. Baekeland, and Elmer A. Sperry on his staff, the Board, for lack of firm direction, made little headway and found its wartime activity limited to screening the tens of thousands of inventions submitted to the Government by a war-stimulated public. A year later, in July 1916, the National Academy of Sciences, with President Wilson's concurrence, formed a National Research Council (NRC) as its operating subsidiary under George E. Hale, director of the Mount Wilson Observatory, to establish cooperation between existing Government, educational, and industrial research organizations. Important posts went to Dr. Stratton of the Bureau and Dr. Charles D. Walcott, Secretary of the Smithsonian Institution and director of NACA, as Government representatives on NRC. Industrial representatives included Gano Dunn of the J. C. White Engineering Corp. and John J. Carty, president of American Telephone & Telegraph; and Michael Pupin of Columbia University represented educational institutions.[5]

In February 1917 the Council of National Defense requested the NRC to act as its agency for the organization of scientific information and personnel, the Naval Consulting Board to act as its committee on inventions. While neutrality tottered, the emergency councils and committees met and waited for a directive. No estimate, not even a guess, could be made of our possible troop commitment. The Nation was perilously close to war, yet few in this country even realized the nature of the conflict in Europe, that apart

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[3] Letter, Secretary of NACA to Secretary of Commerce, Dec. 18, 1915 (NBS Box 3, AG). For further details on the establishment of NACA and its relation to the Bureau, see NBS Box 7, IDS.

NACA, established with an appropriation of $5,000, or "such part thereof as may be needed," was the predecessor of the National Aeronautics and Space Administration (NASA) whose budget in fiscal year 1964 was approximately one million times the initial appropriation to NACA.

[4] Hearings * * * 1919 (Jan. 25, 1918), p. 960. Bureau records for December 1917, said Redfield, indicated that demands for scientific work from the military services came in at the rate of one every 20 minutes during that month (With Congress and Cabinet, New York: Doubleday, Page, 1924, p. 100). By then, Stratton reported (Hearings * * * 1919, p. 960), military research constituted 95 percent of Bureau work.

[5] Letter, Hale to Secretary of Commerce, May 15, 1916 (NBS Box 296, APY-Hale). For the wartime organization of science, see Robert M. Yerkes, ed., The New World of Science: Its Development During the War (New York: Century, 1920), pp. 33 ff.

from a titanic struggle of armies it was a war of technology, of materiel, of massive and mechanized production. But of this the military services showed little cognition. Except for an answer to the growing U-boat menace, neither the Army nor Navy appeared to know what would be required of them or what science and technology could do for them.

Even when war was declared on April 6, 1917, the Nation was slow to awake to the fact that it was unprepared. Few believed that American troops in any number would be involved.[6] Two months later, in a show of the flag, Pershing took token elements of the First Division to France, and a month later cabled home the first unvarnished reports on the desperate plight of the Allied armies. Three years of carnage on a battlefront that had not changed by 10 kilometers in either direction had bled the British white. French morale was at its nadir and the armies close to mutiny. Pershing reported he would need 1 million men by the spring of 1918 and 3,200,000 in France by early 1919.[7]

To send that initial force overseas and produce and supply the mountains of material it must have, the scientific, economic, and social life of the Nation became mobilized as never before in its history.[8] There was no time for long drawn out research. For most of its war machine, the Nation had to rely on the research of the Allies. Artillery, ammunition, communication equipment, aircraft, and armored plate, all of Allied design, had to be adapted to American raw materials and American methods and machines. The scientific resources of the country were to be utilized principally in developing new sources and substitutes for war-scarce materials, devising new instruments and equipment for the Armed Forces, and accelerating standardization and mass production techniques in industry.[9] The demand for weapons, armor, engines, rails, trucks, and other heavy duty equipment was to make it a metallurgists' war; the need for substitute materials, for nitrates, for the agents and materials of gas warfare made it a chemists' war. Confronted at last with the nature of its task, the Council of National Defense began by mobilizing the laboratories of the universities, of industry,

[6] Frederic L. Paxson, American Democracy and the World War, 3 vols. (Boston: Houghton, Mifflin, 1936–48), II, 9.

[7] John J. Pershing, My Experiences in the War (New York: F. A. Stokes, 1931), I, 94–99; II, 122–123. See also Prof. J. S. Ames' report from Europe in May 1917, quoted in The Autobiography of Robert A. Millikan, pp. 157–158.

[8] Neither the Civil War nor the Spanish-American War "presented the necessity to convert to military use the maximum power of the Nation, nor to create for their use elaborate machines and weapons unknown to peace." Where earlier war manufacture was peace manufacture expanded, "in 1917–18 it was new manufacture upon an unknown scale." Paxson, II, 35.

[9] The first important moving assembly line in this country, at the Ford plant just outside Detroit, went into operation in May 1913, cutting the production time of a car from 12 to less than 6 hours.

and Government, and in particular the two Government bureaus "oriented to industrial problems—Standards and Mines." [10]

Until 1917 the war in Europe had little impact on the Bureau of Standards. Personnel increases remained normal, the volume of Government testing rose briefly in 1916 and then subsided, and industrial testing actually declined between 1914 and 1917. Uncertain of their requirements, the military services made few demands. In 1915 the Signal Corps requested some tests of airplane frames, wing fabrics, and engines. The NACA asked for a study of the characteristics of airplane propellers. In 1916 the Navy Department sought tests of steels going into its new warships. That same year Army Ordnance, soon to be swamped in problems, asked only for a study of several failures it had encountered in elevating gun screws.

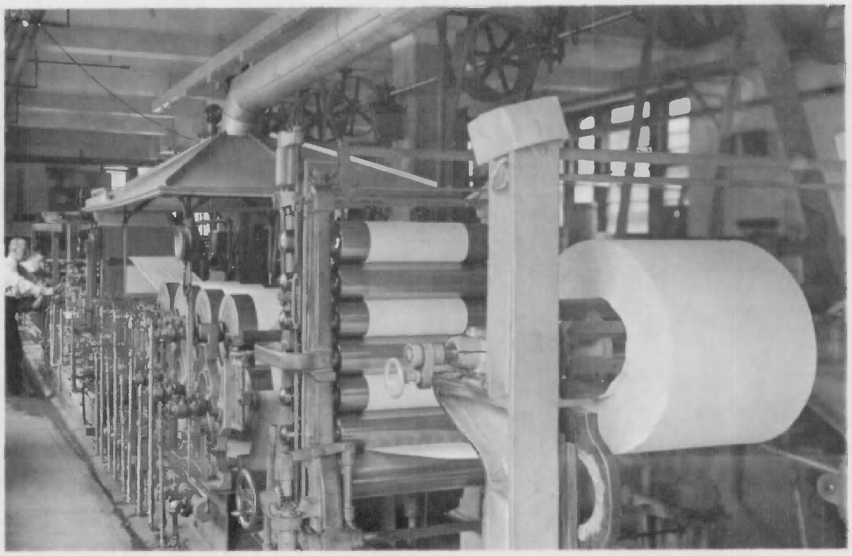
Although heavy industry began producing munitions for the Allies in 1914, no call was made on the Bureau for certification of the gages used in their manufacture.[11] But with something like prescience, Louis A. Fischer urged Dr. Stratton to seek out a gage expert and organize a special laboratory. Harold L. Van Keuren was brought in and set to work planning the laboratory. It was one of the few areas in which this country was prepared when we entered the war.[12] Stratton also became concerned as German sources of chemical laboratory ware and high-grade optical glass were cut off, and early in 1916 he sought funds for additional furnaces and kilns at the Pittsburgh laboratory of the Bureau to undertake their experimental production.

The gage laboratory and glass plant were not the first such resources acquired by the Bureau. Well aware that in the testing of materials, analysis could not be separated from synthesis, Stratton had acquired five of these small-scale "factories" before the war. Learning that the machinery firm of Pusey and Jones in Wilmington was constructing several small paper mills for paper research companies, Stratton had managed to obtain one of

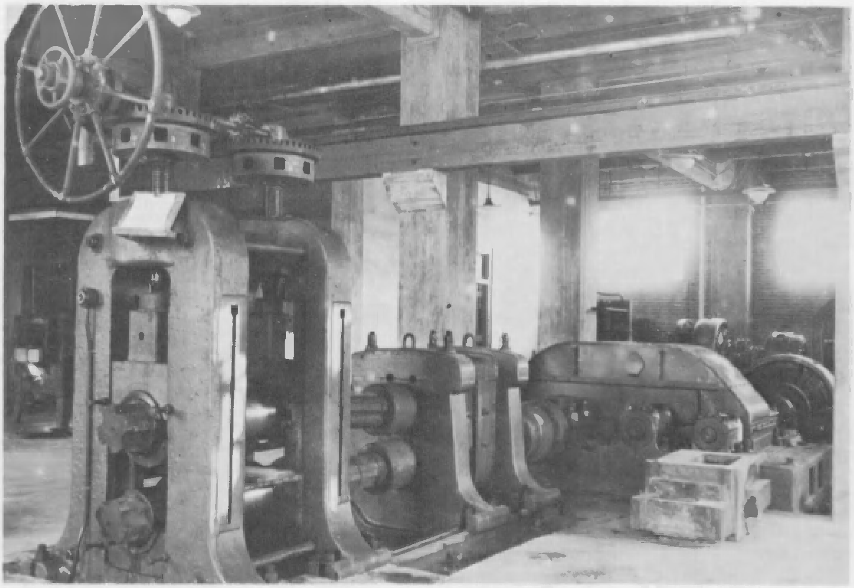
[10] Dupree, Science in the Federal Government, p. 304.

[11] Export of American explosives, principally to England, increased from $6 million in 1914 to $467 million in 1916. Bureau correspondence with the Secretaries of War and Navy in 1915–16 reported that munitions drawings were going to manufacturers with no mention of the necessary gages or with insufficient gages, and warned of the "grave danger that [these war supplies] would not fit when delivered to the field" (NARG 40, file 67009/43). Not surprising, many of the shells on arrival overseas proved to be "of a low standard," and in June 1916 the British War Mission established its own gage testing laboratory in New York. It came too late. In the Battle of the Somme that opened in July 1916, "the faultiness of the [American-made] ammunition in the preliminary artillery barrage was particularly severe * * * [resulting in] numerous premature bursts, falling short of shells, and unexploded shells." Brian Gardner, The Big Push (London: Cassell, 1961), pp. 63, 86.

[12] NBS Annual Report, 1917, pp. 20–21; SWS Address, 15th Annual Conference on Weights and Measures, May 23, 1922 (NBS Historical File).



Above, the NBS small-scale experimental paper mill in which all the operations of paper-making could be studied under controlled conditions. Below, the rotary cement kiln at the Pittsburgh laboratory, brought to Washington in 1918, for determining the effects of various processes in the manufacture of cements.



Above, the experimental rolling mill in the metallurgical division, a 16-inch mill equipped for rolling plates, rods, or bars, both hot and cold. Below, the NBS experimental cotton mill, acquired after the war, showing the knitting machine on the left and the creel (sets of bars with skewers for holding paying-off bobbins) on the right.

them for the Bureau at a fraction of its cost.[13] Components and processes in the manufacture of rubber products were determined on a small rubber mill similarly acquired, in which rubber compounds could be mixed and tubing and other small rubber articles made. The Pittsburgh laboratories had several small-scale kilns for firing clays and clay products, in which the effect of various compositions were determined, and a cement kiln with a capacity of a barrel at a burn. The metallurgical division had both an experimental foundry and a small rolling mill, for the preparation and heat treatment of alloys, where over 3,000 foundry castings were turned out during the war.[14]

With the acquisition of the gage shop and optical glass plant, the Bureau thus had seven of these small plants engaged in special production and process problems all through 1917–18. It was negotiating for two others, a small woolen mill and a cotton mill, as the war ended.

The wartime expansion of the Bureau might be said to date from 1913 when, to the original 8 acres of hilltop, an additional 9 acres were added on three sides of North building. In 1918 another 10 acres to the north gave the Bureau its first frontage on Connecticut Avenue, and small parcels totaling almost 8 acres purchased over the next 2 years brought the site close to its present form, except for the great slope down to the avenue, not acquired until 1925.[15]

New field laboratories of the Bureau included two structural materials (cement testing) stations at Denver and San Francisco, transferred from the Department of Interior's Reclamation Service in July 1917. The next year another cement laboratory, for Army, Navy, and Shipping Board construction projects, was set up at San Diego, and branch laboratories for gage testing were opened in New York, Cleveland, and Bridgeport, Conn.[16] In Washington, the fourth major structure, East building, housing the electrical laboratories, was completed in the spring of 1914. Later that year a large storage and workshop structure called the Far West building went up; a handsome new Chemistry building, begun in 1915, was occupied in

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[13] Conversation with Dr. Robert Hobbs, Feb. 19, 1963.

[14] For descriptions of these plants, see Stratton, "The work of the National Bureau of Standards," an address before the Engineers' Club, Dayton, Ohio, May 4, 1915, pp. 43–45 (in Stratton Papers, MIT), and interview with SWS by H. E. Lobdel, editor, Technology Review (MIT), 24, 7–10 (1922). For the foundry work, see NBS Annual Report 1918, p. 188; Annual Report 1919, p. 263.

[15] See app. L for the sequence of NBS land acquisitions.

[16] NBS Annual Report 1918, p. 139; letter, SWS to Bureau of Public Roads, Department of Agriculture, Jan. 24, 1919 (NBS Box 15, IRC).

Mule teams leveling the ground for the new Chemistry building in the early fall of 1915. The rear of North building and the edge of the Low Temperature laboratory are in the background.

the spring of 1917; and in 1918 the Radio Laboratory and its towers, adjacent to East building, was completed.[17]

Of the hundred-million-dollar National Security and Defense Fund voted by Congress to President Wilson in 1917, a little over $2 million was allotted to the Bureau in 1918–19 for the construction and equipping of two large "war-emergency" laboratories and two lesser structures. Northwest building, centralizing metallurgical research, the gage work, and military equipment and military instrument research, was completed in March 1918, and an imposing Industrial building, almost three times larger than any previous Bureau structure, was finally completed early in 1920.[18]

The first occupants of the Industrial building, moving in late in 1918, were the structural materials laboratories, crowded out of West building, and Dr. Stratton's paper and rubber mills. Into a new Kiln building, back of Industrial, went an enlarged optical glass plant, as well as the cement and ceramic kilns brought from the Pittsburgh laboratory where the Army had commandeered much of the Bureau space for its own use. The fourth structure was an Altitude Laboratory (later called the Dynamometer Laboratory), in which high-altitude conditions could be simulated for testing airplane engine performance under flight conditions.[19]

While the President's emergency fund provided much needed buildings for the Bureau, special wartime funds for military research, amounting to $487,000 in 1917–18 and $622,000 in 1918–19, made it possible for the Bureau to acquire scientists it could never otherwise have afforded.[20] The scientific, technical, and administrative staff rose from 517 in 1917 to 1,117 a year later, some of the newcomers advancing to key positions and

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[17] For construction details of these buildings, see NBS Blue Folder Boxes 77–79, 81. Among minor structures built following the influx of warworkers were the Standard Store and gas station, erected at the entrance to the Bureau grounds and operated by staff members in their off hours. Since the nearest stores were almost a mile away in either direction, the Bureau shop was a convenience, offering fruit, vegetables, canned goods and other groceries, tobacco and sundries, as well as gas and oil, at cost. By 1925 commercial enterprises began to close in, and that spring the store and gas station were closed. Letter, GKB to H. W. Bearce, Dec. 1, 1925 (NBS Box 108, AG).

[18] NBS Blue Folder Boxes 82–84.

[19] For the altitude laboratory, see letter, Secretary of Commerce to President Wilson, Aug. 6, 1918 (NBS Box 5, FPG).

[20] Approximately half the funds were special military appropriations by Congress to the Bureau, the other half transferred funds from Army and Navy appropriations. See app. F.

The Standard Store and gas station down on Connecticut Avenue, at the corner of Van Ness Street (formerly Pierce Mill Road). The recently completed Industrial building is in the background. The Ford passenger-freight van back of the store is being serviced, as a trolley approaches to pick up the waiting soldier and scientist. The year, 1918.

destined to remain at the Bureau through the intervening years between wars.[21]

The universities and, to a lesser extent, industry were to furnish numbers of young scientists needed at the Bureau, but not before the services, indiscriminately accepting or drafting every male of military age, had made serious inroads on the staff. Those with Navy appointments were the first to go, and the cavalry units at nearby Fort Myer carried off a large group, including most of the textile section, before a halt was called.

Dr. Stratton's long reluctance to hire women to work at the Bureau—he is reported to have said once that the sight of his scientists in shirtsleeves might offend them—broke down as the services not only called up many on the clerical and administrative staff but great numbers of the laboratory aids, apprentices, and assistants. While Stratton felt it was not "in the interests of the service to open such positions as assistant or associate

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[21] Statutory employees in December 1918 numbered 341, those paid from special appropriations 424, those from the President's allotment and military funds 295, the remaining 57 on loan from universities and other Government agencies. Hearings * * * 1920 (Dec. 12, 1918), p. 934.

From the universities in 1917 came Dr. Edward Wichers to work in the chemistry of platinum metals; Dr. Fred L. Mohler, a spectroscopist assigned to optical pyrometry in airplane engine research; Dr. Lewis V. Judson, to work on the calibration of military scales; Dr. Henry T. Wensel, on optical lenses and glasses; Laurens E. Whittemore, in radio; and Dr. Englehardt A. Eckhardt, to investigate sound-ranging problems. From industry came Arthur F. Beal (military timepieces), Howard S. Bean (gage testing), Carl S. Cragoe (methane analysis), and Francis W. Dunmore (radio). "Drafted" from other Government agencies as Stratton combed the lists for physicists and chemists were Dr. Lyman J. Briggs, later Director of the Bureau, to work in aviation physics, and Dr. Gustave E. F. Lundell, to do alloy research and head the standard samples section.

In 1918 recent university graduates arriving at the Bureau included Archibald T. McPherson, assigned to gas chemistry studies of combustion engines; Raleigh Gilchrist, analytical chemist in platinum metals; and James I. Hoffman, iron and steel chemist. From industry that year same Ralph E. Gould (timepieces), Enoch Karrer (searchlights), Roman F. Geller (optical glass refractories), and Alexander I. Krynitsky (experimental foundry).

Uniforms appeared on the Bureau grounds as the Army and Navy assigned specialists to work on military assignments, among them Cpl. Frederick A. Curtis, in paper research, and Herbert N. Eaton, in aeronautical instrument research.

Among university personnel on temporary assignment to the Bureau were Dr. Frederick W. Grover, who had been there from 1903 to 1912 and returned to work on radio measurements; Dr. Llewelyn G. Hoxton, who came back to make physical studies on combustion engines; Prof. Albert A. Michelson, in a lieutenant commander's uniform, to work on optical problems for the Navy Department; and Dr. William B. Kouwenhoven, electrical engineer from Johns Hopkins, to make studies in the magnetic testing of rifle barrels.

physicist" to women, and few at that time could qualify, he had no choice in replacing his laboratory assistants.[22]

Almost a hundred girls and women came to the Bureau during the war, among them Miss Johanna Busse, a researcher in thermometry, who in 1929 became chief of that section and held the position until her retirement 20 years later. The first woman with a doctoral degree in physics to work at the Bureau arrived in 1918, to assist in the preparation of a radio handbook for the Signal Corps. A second joined the colorimetry section a year later. From then on the doors were open and the question of ability to qualify was never raised again.[23]

More serious than the exodus prompting the distaff influx, the military services and new war agencies also levied on key Bureau personnel, among them Louis A. Fischer, commissioned a major by Army Ordnance; Roy Ferner, called to the Emergency Fleet; and Rudolph Wig and Joseph Pearson, drafted by the Shipping Board. As requests continued to come in, Stratton did what he could to stop the raids on his staff.[24]

The war ended Dr. Stratton's hours in his private workshop. To attend to new and pressing responsibilities and allow him more time to look after the scientific work going on in the laboratories, he was obliged to seek help with the routine operations of his office. In the fall of 1917 he brought in as his technical assistant, Frederick J. Schlink, an associate physicist in the weights and measures division.[25] As an executive of Consumers' Research in the 1930's, Schlink was to become a gadfly of the Bureau, making use of his experience and knowledge gained there in handling the disposition of incoming technical and scientific mail and administering the Government testing work in his divison.

Acquiring personnel was in some respects the Bureau's most difficult wartime problem. Shifting from peacetime to military research was almost the least. So much of its work before the war was keyed directly or indirectly to industry that at congressional hearings on appropriations for 1917, Stratton had no difficulty in pointing out the wartime potential of every investigation at the Bureau. Asking for increases in funds for these investigations and proposing four new ones, in color standards, clay products, the physical

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[22] Letter, SWS to Secretary of Commerce, May 25, 1918, and attached correspondence (NBS Box 4, AP 1917).

[23] Dr. Louise McDowell, Cornell, 1909, on leave from the physics department at Wellesley College, remained through 1918–19. Dr. Mabel K. Frehafer in colorimetry remained from 1919 to 1923. Interview with Dr. Silsbee, May 23, 1963.

[24] See letter, Secretary of Commerce to President Wilson, June 6, 1918 (NBS Box 4, AP).

[25] Hearings * * * 1918 (Dec. 1, 1916), p. 470.

constants of metals and alloys, and standardization of machines, mechanical appliances, and tools, he declared:

> There never was a time in the history of the country when we should be looking at such matters as critically as at present. The items submitted—I think I can say all of them—are as fundamentally concerned with both industrial and military preparedness as any that will come before you.[26]

When war came, Stratton later said, it was not necessary to "change the bureau's organization one bit." [27] The metallurgy division turned from its rail and wheel investigations to armament steel research, the electrochemistry section took up battery research, the electrolysis section turned to sound-ranging problems, and the weights and measures division undertook the preparation of military scales and gage testing. Photometry turned to searchlight and other military illumination projects, pyrometry to optical glass and aeronautical engine research, radiometry studied invisible signaling devices, spectroscopy worked on military photography, and colorimetry took up problems of camouflage. As still other inquiries and requests for research poured in from the military services, from the NACA and the National Research Council, and from the civilian war agencies—the Shipping Board, the War Industries Board, the War Trade Board, the Railroad Administration, the Fuel Administration—the Bureau shifted its electrical, optical, and chemical investigations and its structural and industrial materials programs to their military applications with scarcely a hitch.[28]

NEW SOURCES, RESOURCES, AND SUBSTITUTES

The 299-page report, "The War Work of the Bureau of Standards," suggests that except in medicine and foodstuffs, there was scarcely an investigation of the National Research Council or War Industries Board or a problem of the military services in which the Bureau was not concerned in one way or another. From aircraft construction to camouflage, from coke-oven investigations to concrete ships, from precision gages to illuminating shells, from optical glass to rubber, from submarine detection to X-ray and radium research, the Bureau participated in almost the whole range of America's wartime effort. As standards laboratory and as research institute

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[26] Hearings * * * 1917 (Feb. 2, 1916), pp. 991–992.
[27] Hearings * * * 1919 (Jan. 25, 1918), p. 975.
[28] For a roster of the scientific staff and the wartime projects of the Bureau as of September 1918, see app. J.

it was called on to (1) furnish scientific and technical information and recommendations, (2) undertake specific research, (3) develop and standardize tests and test procedures, (4) standardize materials and equipment, and (5) make new as well as routine precision measurements.

The first direct contact of the Bureau with the war in Europe occurred in the spring and summer of 1917 when members of the Bureau went abroad with a scientific mission "to obtain information concerning applications of science to warfare and the part to be played by scientific men in the war." [29] That same spring British and French scientific missions arrived in this country and visited the Bureau, bringing with them new military equipment, products of their laboratory research and battlefield experience. The disclosures of both missions were jolting, for they indicated a range of research abroad of which we were entirely ignorant and a superiority in certain technologies of which we were wholly unaware. Particularly impressive were some of the French steels and semi-steels and the developments of French radio apparatus.[30]

Chemicals and steel, forging the weapons of the battle in France, were primary concerns of the Bureau throughout the war. Germany's preeminent dye industry, on which our textile industry depended for 90 percent of its dyestuffs, also made her dominant in explosives, for out of the same coal tar derivatives that built the aniline industry came the phenol for picric acid, the toluol for TNT, and the ammonia for ammonium nitrate.[31] This country's negligible dye industry made us almost wholly dependent on the coking industry for our supply of toluol. When war came that supply was already earmarked for the Allies and other sources had to be speedily developed. In the spring of 1917, at the instigation of the National Research Council, Bureau representatives met with American Gas Institute officials and with Federal, State, and city authorities to study procedures for the recovery of toluol from city gas supplies, as the British were doing, and to determine the adjustments necessary in standards of gas service.[32]

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[29] NBS M46, "The War Work of the Bureau of Standards" (1921), pp. 11, 172. Hereafter cited as "War Work."

[30] The steel in the French 240-mm. trench mortar, for example, was much better than that in the same mortar made in this country. The French also made a satisfactory processed cast iron (semi-steel) shell that American industry was unable to duplicate until the Bureau established criteria for its production. See "War Work," pp. 195–196. For the radio equipment of the Allies, see radio section, below. On the other hand, the Bureau discounted the new stainless steel made by the English and even after the war continued to believe it had only limited usefulness. See letter, SWS to Chief of Construction, Navy Department, Dec. 21, 1921 and attached correspondence (NBS Box 12, IMH).

[31] Letter, Secretary of Commerce Redfield to SWS, Feb. 22, 1915 (NBS Box 3, AG).

[32] See Benedict Crowell, America's Munitions, 1917–18 (Washington, D.C., 1919), pp. 107–108.

Constructed on the basis of Bureau recommendations, 21 Government-owned toluol plants were in operation extracting toluol and ammonia from the light oils of coal and water gas in city gas works at the time of the armistice. The reduced efficiency of household gas that resulted from this stripping became a memorable experience of the war as heating values fell off and gas mantles roared as housewives turned them up full to get more light. But along with new coke-oven recovery processes, the plants raised toluol production from the prewar rate of approximately half a million gallons annually to 40 times that amount.[33]

The Bureau also became involved in byproduct coke operations when in the latter part of 1917 the Department of Commerce asked Bureau gas engineers to study the recently developed Roberts coke oven, said to produce a commercial grade of metallurgical coke from the low-grade coals of Illinois and Indiana, as well as large yields of byproducts, including light oils, ammonia, and tar. With Bureau of Mines and Geological Survey representatives, more than 20 members of the Bureau took part in the work and continued the investigations through 1918. The war ended before the Roberts oven was proved, but the investigation indicated that the process had considerable merit. Perhaps more important was the reassessment of the value of some of the midcontinent coals as a new fuel and byproduct resource. Although considered uneconomical to work in peacetime, it seemed possible that new advances in mining technology might make them competitive with established fields.[34]

The most extensive testing undertaken by the Bureau during the war was almost certainly in the chemical, physical, and structural properties of metals—of processed-irons for use in shells; of steels and steel alloys for guns, munitions, armor plate, high-speed tools, gages, airplane instruments and engines, helmets and gas masks, horseshoe nails and rivets; of aluminum for metal airplanes and Army canteens; of brass for ammunition. Under the stimulus of war, industry turned out scores of new alloy steels—nickel, chromium, tungsten, zirconium, molybdenum, vanadium, manganese, and cobalt—and sent them to the Bureau for precise determination of their composition and qualities. Ingots of light armor alloy steels (containing zirconium, molybdenum, boron, cerium), made for the Navy at the Bureau of Mines were rolled into plates in the Bureau of Standards mill and thorough tests made of their mechanical, chemical, and thermal properties. And

[33] "War Work," pp. 288–293; T117, "Toluol recovery" (McBride, Reinicker, Dunkley, 1918). For the less than cooperative attitude of the gas industry at the time, see letter, SWS to editor, Am. Gas Eng. J., Nov. 17, 1917 (NBS Box 7, ICG).
[34] "War Work," pp. 73–82.

where tests of new alloys warranted it, the Bureau evolved standard test methods and manufacturing control procedures.[35]

At the request of the NACA and the Navy, studies were made of the properties and methods of manufacture of light alloys of aluminum, for the construction of a proposed all-metal airplane, and of duralumin, known to be used in the construction of the German zeppelins.[36] Cooperating with the War Industries Board in its drive to conserve imported tin, the Bureau found cadmium an acceptable substitute in tin-lead solders. It also made recommendations for the reduction of tin in bearing metals, modified the tin content in bronzes, and contributed to recovery processes for tin scrap. Similar research to conserve manganese, in short supply throughout the war, lead to revised specifications of the manganese content in several types of steel.[37]

In these metallurgical investigations the Bureau introduced, in many instances for the first time, new concepts of quantitative measurement in the industry. Under "cookery" methods of manufacture, still prevalent in many plants, adding a variable quantity of manganese, for example, and the necessary fluxes, resulted in a satisfactory steel and industry was therefore content. Bureau laboratory and foundry research showed that even better steel resulted from exact measurement of its ingredients, and besides conserving raw materials this precision made possible greater control over the manufacturing process.

New technologies and the all-consuming nature of the war soon produced shortages never before envisaged. One of these was in platinum, imported largely from Russia. It was needed in large quantities as a catalyst in the manufacture of munitions, was used in the contact points of airplane magnetos, and in the making of chemical laboratory ware. As it grew scarce its price soared, and hunting for platinum ores in this country became as avid a pursuit in World War I as uranium hunting was to be some 25 years later.

Despite its importance to industry, very little was known about the rhodium, iridium, palladium, iron and other metals found as alloys in commerical platinum or about their effect on manufacturing processes. The study of platinum and the platinum metals which began during the war under

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[35] "War Work," pp. 158–172. A supersteel rumored to be possessed by the Germans and thought to be a zirconium alloy was identified after the war as a uranium alloy, of more propaganda than military or industrial value. See letter, director, Nela Research Laboratory to SWS, July 28, 1917 (NBS Box 11, IM); correspondence in NBS Boxes 10 and 11, IM 1918; interview with Dr. Raleigh Gilchrist, Oct. 30, 1962.

[36] For the Bureau's many years of interest in duralumin (1917–35), see correspondence in NBS Box 384, IM.

[37] "War Work," pp. 154–158, 160–162. See T109, "Conservation of tin in bearing metals, bronzes, and solders" (Burgess and Woodward, 1919).

a special appropriation continued at the Bureau for almost 30 years. The wartime effort was limited to studying the effects of the metals alloyed with platinum when platinum was used for catalytic purposes, assaying the hopeful finds of platinum prospectors—mostly negative—and searching for platinum substitutes. Although Bureau research showed that two gold-palladium alloys known as palau and rhotanium made fairly suitable platinum substitutes in the making of laboratory crucibles and dishes, they were not to be more than wartime expedients.[38]

Since the whole of steel production was preempted for Allied arms and munitions, for war emergency buildings and plants, and for our own weaponry, it seemed for a time impossible to provide sufficient steel to build the transports and merchant fleet this country needed but did not have. Actually, by expansion of existing steel plants and almost total suppression of the automobile industry, the necessary steel plate was made available, but not before a number of wooden ships and even some of concrete came down the ways. It was in the latter program that the Bureau laboratory at Pittsburgh had a considerable role, assisting in the development of a burnt clay aggregate that expanded "like a loaf of bread when it rises," as Stratton said, and yet was strong enough to make concrete ships possible.[39]

Based on designs prepared under the direction of Rudolph J. Wig and Joseph C. Pearson, Bureau members with the Shipping Board, more than 40 concrete cargo ships and tankers were planned. Two experimental ships of 3,500 tons were floated and satisfactorily tested in 1918 and 10 more of 7,500 tons deadweight were completed by 1921. None ever became operational. Although somewhat cheaper and faster to build than steel ships, concrete bottoms by reason of their relative brittleness and reduced cargo space were not deemed likely to replace steel or wood except in an emergency. The same held true of the several concrete barges and concrete freight cars tested by the Bureau.[40]

The months of the emergency disclosed unsuspected gaps everywhere in this country's long vaunted belief in its self-sufficiency. Within weeks of the declaration of war, leather, paper, and textiles went on the list of critical materials and the search for substitutes began. Among leather substitutes produced by industry at the urging of the Council of National Defense and the War Department and tested at the Bureau were fishskin, porpoise, and sharkskin as uppers for civilian and military shoes and a variety of compositions for soles. When it was found that no fishskin would do, the shoe

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[38] "War Work," pp. 65–66, 159–60; Raleigh Gilchrist, MS, "The scientific activities of Division 5 * * * 1917–61," pp. 15–18 (NBS Historical File).

[39] Hearings * * * 1920 (Dec. 12, 1918), p. 947.

[40] Proc. Am. Concrete Inst. 14, 441 (1918); ibid., 15, 241 (1919); ibid., 17, 284 (1921); "War Work," pp. 86–87, 213; letter, SWS to R. J. Wig, Apr. 23, 1918, and attached correspondence (NBS Box 7, ICP).

industry ceased making high-buttoned shoes, at one stroke solving the problem of civilian uppers and making a genuine contribution, however temporary, to foot comfort and esthetics. On the other hand, at least one of the hundreds of composition soles submitted to the Bureau proved almost as durable as leather under ordinary usage, though unsuitable for shoes destined for hard wear overseas.[41] The infantry got the leather.

Bureau tests of paper substitutes and the search for new uses for paper were more successful, resulting, in a critical area, in partial replacement of tin cans by impregnated paper containers for shipping greases and soaps, and paper barrels for shipping pitch or asphalt. A paper made in the Bureau mill from jute and manila rope stock appeared especially promising. An exceedingly strong paper, it was intended as a substitute for the linen fabrics used to cover airplane wings. But it came too late. The substitute actually used for scarce linen was a mercerized cotton fabric developed in the textile section of the Bureau. It was adopted by this country and also by England, whose inadequate supply of flax for linen had made the research necessary.[42]

Faced with the fact that 65 percent of our raw wool came from abroad, that shipping was scarce and uncertain, and that millions of uniforms and blankets would be needed for the American armies coming into being, the Quartermaster Corps and Ordnance Department appealed to the Bureau for help. To find out what characteristics a wool substitute must have, the Bureau sent inquiries to textile manufacturers concerning the nature of the raw stock and woolen compositions. The answers disclosed that neither here nor abroad had manufacturers ever made clothing materials, woolen or otherwise, with specifications that could be quantitatively measured. Wool was wool, as cotton was cotton, whatever the quality or properties of their ingredients. When the industry protested Bureau proposals to define wool compositions and set up specifications, Stratton began negotiations for a small experimental wool manufacturing plant to make the necessary tests. Working the raw materials with available laboratory equipment, the Bureau found that the heat-retaining properties of wool, as well as other textiles, depends less upon the intrinsic properties of their fibers than on their arrangement, and that a lightweight cotton could be made into almost as warm a fabric as wool.[43] The Bureau thus learned that, as in some areas of the steel, glass, and other industries, the textile industry worked with little understanding of its fundamental principles.

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[41] "War Work," pp. 143–144.

[42] "War Work," pp. 198–202, 282; correspondence in NBS Box 15, IST. For other leather, paper, and textile substitutes (wooden soles for shoes, cotton currency, transparent silk for airplane wing coverings, etc.), see NBS Box 15, files, ISL, ISP, and IST. Also letter, SWS to National War Savings Committee, June 11, 1918 (NBS Box 6, IC).

[43] "War Work," pp. 283–284.

As with so many of the wartime investigations, the war ended before much of the research in substitutes could be translated into new products. In the emergency, the quickest solution was often elimination, as in the case of uppers on shoes. Wool simply disappeared from shops and stores and went into uniforms. Felt, too, went off the market and into canteen cases and helmets, splints, and shell packing. Silk went into powder bags. But elimination alone was not enough. To continue to supply the Allies and at the same time clothe, feed, and equip our military forces demanded an end to traditionally wasteful practices and a hitherto unknown degree of standardization. Thus, perhaps the most important result of the search for new sources or substitutes for materials in critical supply was not the substitutes themselves but the fact that both Government and industry were forced to establish specifications for materials and insist on greater standardization of products.

The drive for standardization and elimination of waste in commercial and industrial practices had its beginning in the Commercial Economy Board, organized in the Council of National Defense in March 1917. Renamed the Conservation Division, it was transferred in May 1918 to Bernard Baruch's War Industries Board, soon to regulate the manufacture of some 30,000 articles of commerce.[44]

In the year and a half of the war the Conservation Division and its predecessor effected enormous savings of manpower and materials in over 250 industries by reducing the number of styles, varieties, sizes, and colors, by eliminating services and certain materials and products altogether, by substituting plentiful for scarce materials, and by standardizing sizes, lengths, widths, and weights. The clothing industry was revolutionized from the skin out as steel for corsets, weighted silks, and heavy woolens disappeared from the market. Fabric was saved by shortening men's coats, eliminating outside pockets on suits, and restricting suit styles to 10 models. Shoe lasts were reduced in number and shoe colors restricted to black, white, and one shade of tan.

Newsprint for papers and magazines was cut as much as 20 percent. Colors of typewriter ribbons shrank from 150 to 5 and were sold in heavy paper instead of tinfoil and tin boxes. Buggy wheels were reduced from 232 sizes and varieties to 4, plows from 326 to 76 sizes and styles, and automobile tires from 287 types to 9. Brass pens were abolished, pocketknives

[44] At the same time, Herbert Hoover's Food Administration began fixing food prices, to forestall hoarding and profiteering, inaugurated "meatless" and "wheatless" days, campaigned for other food economies in the home, and acted to stimulate food production. "Hooverizing" enabled the United States to export almost three times her normal amounts of breadstuffs, meats, and sugar in 1918. Mark Sullivan, Our Times: The United States, 1900–1925. V. Over Here, 1914–1918 (New York: Scribner, 1933), pp. 383–384, 418–422.

cut from 6,000 to a hundred varieties, and steel pens reduced from 132 to 30 styles. Mail order catalogs best reflected the new austerity as their customary bulk fell away by more than half.

As a result of simplification and standardization, labor savings in the manufacture of products from clothing to coffins reportedly reached as high as 35 percent. Savings over prewar consumption of materials in some instances rose to 50 percent as simplicity ruled and plentiful wood, paper, zinc, and cotton replaced the steel, tinplate, copper, brass, bronze, pig tin, nickel, and raw wool consumed by war.[45] The country had experienced nothing like it before, and the impact of this husbandry of resources reached into every home, every office, factory, institution, and government agency in the Nation.

Reviewing the wartime economy drive shortly after the armistice, the Bureau had to admit that despite more than a decade of testing of Government purchases,

> no very pronounced demand for standardization among * * * the different Government departments * * * had existed prior to the war. Large as the orders for * * * materials had been in normal times, the necessity for complete standardization was not very evident. When, however, as a result of the war many Government bureaus [began] buying goods of about the same kind at the same time, it soon became necessary to have some sort of standard specifications.[46]

It must be admitted that in the case of the military departments, which had been left free to develop their own purchasing procedures, the new order of the day, for all its intrinsic value, permitted a latitude of interpretation that sometimes worked mischief. Specifications arbitrarily arrived at often defeated their purpose, as when General Electric complained to the Bureau that it frequently received greatly differing specifications for identical items of electrical apparatus ordered by the Army and Navy.[47] Asked at a congressional hearing why the Government had requirements or specifications that manufacturers found all but impossible to meet, Stratton replied that these were not Bureau specifications. New department or bureau heads, particularly in the War Department, who suddenly became "specification-minded" were apt to set up standards for materials on their own initiative

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[45] Grosvenor B. Clarkson, Industrial America in the World War: The Strategy Behind the Line, 1917–1918 (Boston: Houghton, Mifflin, 1924), pp. 209–231; Bernard M. Baruch, American Industry in the War: A Report of the War Industries Board (1921), edited by R. H. Hippelhauser (New York: Prentice-Hall, 1941), pp. 65–69.

[46] War Work, pp. 151–152.

[47] Letter, General Electric to NBS, Mar. 10, 1917 (NBS Box 7, IE). For a note on the Standardization Section of the General Staff, set up in August 1918, see NBS Annual Report 1919, p. 52.

that could be produced only at high cost. The tensile strength established for one kind of steel wire, for example, had proved clearly beyond the requirements and wholly impractical to make. In another case the Bureau found that a cement specification so limited the magnesium content that it cut off the most important cement-producing district in the United Sates.[48] And in at least one instance the War Industries Board had to act "to kill a general standardization suggestion that evolved in the War Department during an attack of unusually severe standardization fever. To have reduced all machine tools to uniform standards [as recommended] would have stifled production for many months." [49]

Despite the follies committed in the name of standardization, the practice emerged from the war as an indispensable consideration in the coming age of mass production. The war demonstrated not only the usefulness to manufacturers of specifications and standards, as the Bureau had long and patiently pointed out, but their inescapable necessity. For the Bureau to have supplied in those few months the thousands of standards asked for by agencies and industries in the grip of war was out of the question. The major effort of the Bureau was restricted to an attempt to codify Government procedures and to formulate, where it could, responsible and comprehensive specifications for materials and products it was equipped and staffed to deal with.[50]

The hope of the Bureau that the impulse toward conservation, toward sensible husbandry of resources through standardization, might continue in the postwar period was soon dashed. Industry no sooner turned from war production to the consumer market again than it reverted to all its former wasteful practices. It was brought up short by the severe postwar depression that struck late in 1920. Under the leadership of the Department of Commerce and the National Bureau of Standards, industry was again instructed in its wartime lesson. Conservation and standardization became key words of the decade.

THE AIRPLANE IN THE LABORATORY

So rapid was the wartime development of air power and air strategy that by 1917 some at the Bureau seriously believed that "victory was likely to go to the side having the largest and most effective types of machines.[51] Yet in no aspect of scientific, technological, or industrial capability was America so utterly unprepared as it was in aviation. The airplane that first

[48] Hearings * * * 1920 (Dec. 12, 1918), pp. 929, 945.
[49] Clarkson, Industrial America in the World War, p. 454.
[50] "War Work," p. 16.
[51] Ibid.

flew at Kitty Hawk had continued to evolve in Europe, where the early years of the war saw successively improved military planes and power plants—the enemy and Allied artillery spotters, scouts, pursuit craft, and great lumbering bombers—whose designs were carefully withheld from neutrals. In the same decade and a half after the Wright brothers' flight, the military forces of this country had acquired just 2 flying fields and 55 planes. Every one of those planes was either obsolete or obsolescent by European standards and had little or none of the instrumentation in the aircraft then flying in France.[52]

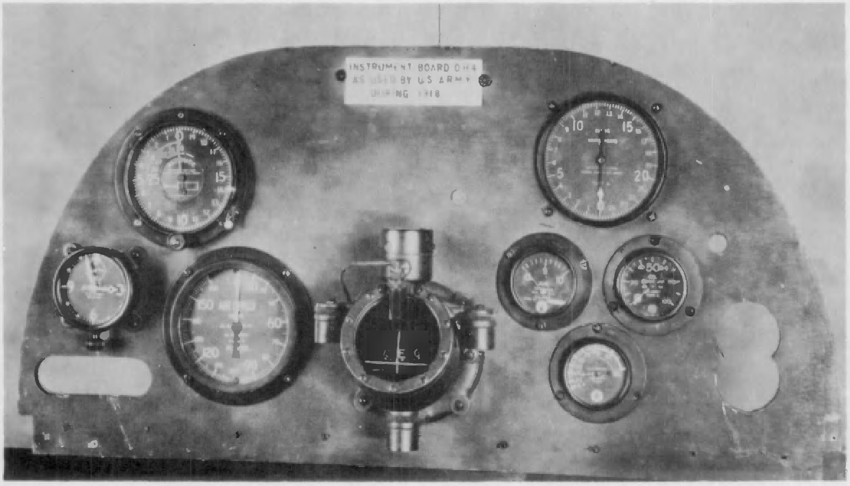
With our entry into the war, the Allies at once made their airplane designs available. On the other hand, because this country was supplying parts, some of their engine and instrument difficulties had arrived here earlier, through the war missions. Reports from abroad in 1916 indicated a number of shortcomings in their new high-powered planes. The spark plugs in use were said to limit better engine design, engine fuels were erratic in performance, and the lubricating oils often congealed at high altitudes. Bombers, fighters, and reconnaissance planes all required more refined instrumentation and, more important, improved wing fabrics and dopes, to reduce their vulnerability to fire. Other questions laid before the Bureau through the National Advisory Committee for Aeronautics and the Bureau of Aircraft Production in the Signal Corps included determination of the rate of flame propagation and of pressure cycles in aviation engine cylinders and better design of engine radiators.

Bureau ignition experts found that besides the high carbon deposits that frequently formed on the American-made spark plugs used by the Allies, sudden extremes of heat and cold at high altitude (10,000 to 30,000 feet) sometimes cracked the porcelain insulators, or the high heat alone caused the insulators to become conductors of electricity, resulting in the engine sudddenly cutting out in flight.[53] The Bureau discovered that these failures occurred principally because of poor materials or poor workmanship, and sent to manufacturers of ignition equipment the data it had collected, along with new specifications and standard test methods to insure a better product. Before the war ended the Bureau's electrical and ceramic divisions had devised a much improved arrangement of engine circuits and produced a better type of porcelain for aviation spark plugs.[54] The work continued

[52] Leonard P. Ayres, The War With Germany: A Statistical Summary (Washington, D.C., 1919), p. 85.

[53] Letter, General Electric to Chief Signal Officer, Nov. 22, 1917 (NBS Box 9, IEP), declared: "If we are correctly informed, the spark plug, as at present developed, is one of the weakest points in the equipment of the modern aeroplane."

[54] Silsbee, "Ignition work at the Bureau of Standards," Automotive Industries, nv, 1294–1299 (June 12, 1919); "War Work," pp. 24–30.



The instrument panel in the De Havilland–4 of 1918. Most of the instruments shown were of European origin, all modified by the Bureau before adoption as U.S. Army standard for the De Havilland.

after the war in a new power plant section set up in the heat division at the Bureau.

All of the altimeters, airspeed indicators, tachometers, and other aeronautical instruments that came to the Bureau for examination and testing were based on European prototypes. Many were still in an elementary stage and underwent considerable modification in the laboratories prior to their adoption as standard by our Army and Navy. Successive modifications of the inclinometer or banking indicator led to an almost wholly new instrument. The same was true of the rate-of-climb indicator, whose inherent defects could not otherwise be eliminated.[55]

If instrumentation and engine problems were to a degree overcome by the end of the war, time militated against getting the highly publicized "cloud" of American planes into the air. When in July 1917, the Signal Corps was directed by Congress to design and build a fleet of 22,000 planes, neither the military services nor American industry had developed a single modern airframe or engine. A year was simply not time enough to acquire the necessary skills or experience, and the Government's overambitious program resulted in fewer than 700 planes. These were chiefly flying boats and observation planes, the latter principally a redesigned De Havilland–4, called by the American pilots who took them up, the Flying Coffin.[56]

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[55] "War Work," pp. 11–16, 38–40; NBS Annual Report 1919, pp. 186–187.

[56] George C. Reinhardt and William R. Kintner, The Haphazard Years: How America Has Gone to War (New York: Doubleday, 1960), p. 80.

Except for the pioneer work of the Wright brothers, Langley, Chanute and a few others, serious study of the scientific fundamentals of flight began in this country only after the NACA requested the Bureau in 1915 to undertake an investigation of aviation aerodynamics. The Bureau was to play an important part in this research before the NACA acquired facilities of its own.

In January 1918 the Bureau transferred its aerodynamic studies from the library and laboratory to a new wind tunnel building recently constructed under the direction of Dr. Lyman J. Briggs. Dr. Briggs, a Department of Agriculture physicist lent to the Bureau several months earlier, recalled that soon after he arrived Dr. Stratton asked him to design and build a wind tunnel balance. Asked whether he knew what that was, Briggs answered that he presumed it was "to measure forces on an airfoil." "Right," said Stratton, "and while you're about it, you'd better design a wind tunnel to put it in." [57]

The wind tunnel that Briggs designed housed a 9-foot propeller that produced air speeds of 90 miles an hour. In it he installed recording apparatus and began his measurements on airfoils and on airplane and dirigible models. In almost continuous operation, the wind tunnel was also used to make studies of wind stresses, to test airspeed indicators and similar instruments, and to determine the flight characteristics of aerial bombs.

While the aircraft program as a whole lagged for lack of time, knowledge, and experience, aviation engine production, utilizing the Nation's automotive industry, quickly went into high gear. Both as a matter of national prestige and practicality, an American-designed engine was considered crucial from the start. Although an aircraft commission sent to Europe in the spring of 1917 examined more than 80 different engines in use or under development by the Allies, none was deemed sufficiently powerful to meet future requirements or, what was more important, lend itself to mass production methods or materials.[58]

Design work on both 8-cylinder and 12-cylinder engines was started that June by a group of Packard Motor Car engineers quartered at the Bureau. They had begun the preliminary paperwork in the Washington hotel where they were staying and were ready to start on the detailed manufacturing drawings when they phoned Dr. Stratton one midnight and told him they needed more space. He promptly made available the whole of the new Chemistry building and the use of any other facilities at the Bureau they might need. The engineers moved in the following morning.[59]

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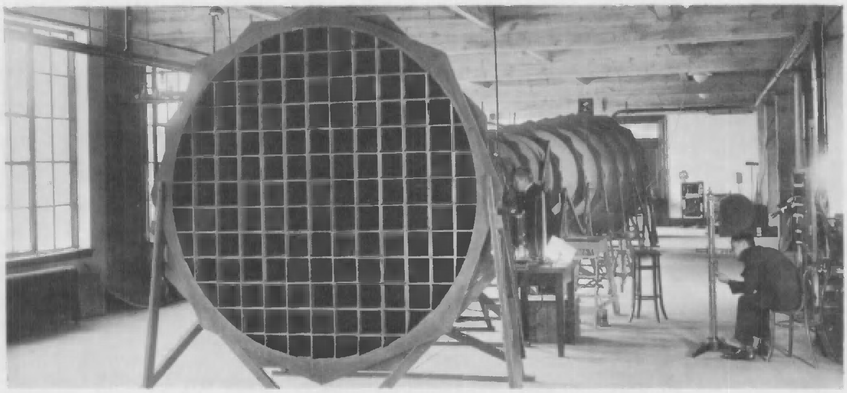
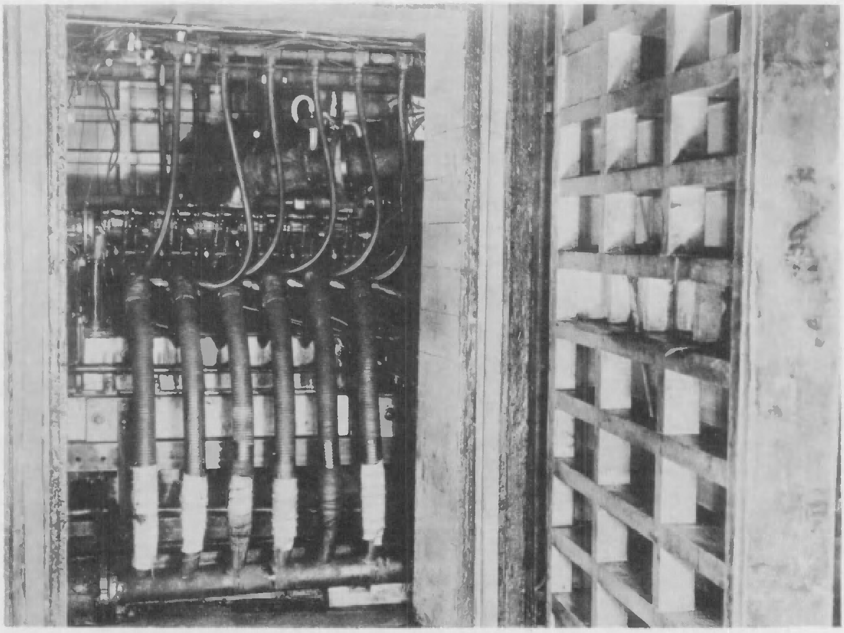
[57] Interview with Dr. Briggs, Nov. 1, 1961; NBS Annual Report 1918, pp. 127–128.

[58] Redfield, With Congress and Cabinet, p. 227; Paxson, American Democracy and the World War, II, 112.

[59] Crowell, America's Munitions, 1917–18, p. 270.



The Bureau's second wind tunnel as set up in Northwest building late in 1919. The honeycomb at the entrance of the 3-foot wind tunnel steadied the incoming flow of air. The maximum wind speed that could be established was about 150 miles per hour, more than enough to determine the air resistance of bombs, projectiles, airplane models, and for calibrating instruments.



The 12-cylinder Liberty engine mounted for testing in the Bureau's altitude chamber. When both concrete side doors (one open here) were closed, the air pressure and temperature inside could be lowered to correspond to any desired altitude, making it possible to test the engine under simulated flying conditions.

The exhaust from the engine and the air in the chamber were withdrawn by an electric-driven centrifugal exhauster. The pressure could thus be reduced as low as one-third of an atmosphere, corresponding to an altitude of approximately 35,000 feet.

But so rapidly was aviation history moving that 1 month later, when the first 8-cylinder engine arrived at the Bureau for testing, it was declared inadequate. Pershing had cabled that the planes he would need for his operations in 1918 must have 12-cylinder engines. Exactly 2 months after, in September 1917, the "12," putting out over 300 (later more than 400) horsepower, as against the 225 horsepower of the "8," had arrived and successfully passed its 50-hour test. Originally named the "United States Standard 12-cylinder Aviation Engine," it was rechristened the "Liberty engine" as it went into production 4 months later. Up to the armistice, the Packard, Lincoln, Ford, Cadillac, Buick, and Marmon factories built 13,574 Liberty engines, of which fully a quarter went overseas to the AEF and the Allied air services.[60]

In preparation for tests of the Liberty engine, special dynamometer and altitude laboratories were erected on the Bureau grounds for performance studies of the engine under simulated flight conditions.[61] (The temporary structures were later combined in a permanent Dynamometer Laboratory, built adjacent to Northwest building.) Construction of the altitude laboratory, in which conditions of low air pressure and cold encountered at great heights could be established, was a tremendous engineering feat, and for a time the chamber was the only one of its kind in existence.

Liberty engines, as well as Rolls-Royce, Hispano-Suiza, Fiat, Bugatti and other engines made by the Allies underwent endless tests and measurements of the effects of altitude on carburetor performance, on radiators, fuels, lubricating oils, and on supercharging devices designed to enable planes to attain higher altitudes.[62] Of considerable importance at the time were the Bureau studies in its chemical and altitude laboratories on the conservation

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[60] Crowell, pp. 273, 277, 280; Ayres, The War With Germany, p. 90.

Stoutly defending what some claimed was "a cooperative monstrosity," Secretary Redfield said that Liberty engines after the war went into the planes of the airmail service inaugurated by the postal service in 1921, powered the transatlantic flight of the Navy NC–4 (Halifax to Lisbon) in 1919, and held all transcontinental record flights and world's altitude, speed, and endurance record flights up to 1923 (Redfield, With Congress and Cabinet, pp. 298–299). Stratton, too, thought it a fine engine, pointing out that it had 200 fewer parts than European equivalents and developed 475 hp., where the most powerful European engine had less than 300 hp. Letter, SWS to Airplane Engineering Department, Signal Corps, June 7, 1918, and attached correspondence (NBS Box 16, ITA).

[61] Fourth Annual Report, NACA, 1918, pp. 483–498; NBS Annual Report 1917, pp. 110–111.

[62] "Lubrication presented its problems, because the engineers believed that no other lubricant possessed all the advantages of castor oil," and the Army Signal Corps called for the planting of 100,000 acres to the castor-oil bean in this country. Paxson, American Democracy and the World War, II, 269; letter, Director, Aircraft Production to SWS, Oct. 11, 1918, and attached correspondence (NBS Box 16, ITAL).

of petroleum. They yielded the first quantitative data reported anywhere on the power-producing qualities of gasolines, and resulted in liberalizing the excessively rigid specifications set by the French for the aviation gasoline we were sending them, and incidentally were using ourselves.[63]

Designing an engine to lift the vast Government airplane program off the ground was only half the task. New woods or wood substitutes had to be found for airframes and materials for covering wings and fuselages. Spruce, considered most suitable for airplane construction, became scarce through oversea demands even before we entered the war. In exhaustive tests of proposed substitutes, more than 20 other kinds of wood, shaped as ribs, beams, and struts, went under the impact- and fatigue-testing machines of the Bureau. Although a laminated spruce, made of the waste in solid-beam construction, proved satisfactory, it was considered too costly, and only beams of fir showed practical promise.

The spruce shortage and the desirability of building a nonflammable, or at least fire-resistant, plane led to a great deal of work on metal airplane parts. Several sheet metal companies even proposed an all-metal plane, similar to the German Fokker introduced early in 1918. The companies were far from encouraged when the wings on one all-metal mockup sent to the Bureau for testing proved to have a low safety factor. The plane went back for redesign.[64]

Metal wing and fuselage frames seemed more promising, and numerous alloy steels were tested before attention finally centered on aluminum. Weight for weight, some of the structural beams of aluminum ranked well above Sitka spruce in strength tests, and in test flights an experimental plane with wing beams and ribs of aluminum demonstrated "the possibility of the successful manufacture of airplanes with metal-wing frames." [65] Only the discovery of a satisfactory nonflammable or fire-resistant wing and fuselage covering remained, and this problem had still not been solved when hostilities ceased.

The development of an acceptable mercerized cotton fabric and even a strong paper of jute and manila rope stock as substitutes for linen in airplane wing construction has already been mentioned. No form of glue or adhesive, however, could be found that would fasten either cotton or paper to the frame and at the same time render them waterproof and fireproof. For this purpose, better airplane dopes had to be found.

A cellulose acetate made in Germany by Bayer was the dope usually applied to the fabric on wing and fuselage, in order to shrink the material,

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[63] "War Work," pp. 16–24, 30–32; NBS Annual Report 1919, p. 26.

[64] "War Work," p. 33. For another all-metal design turned down by the Bureau, see letter, SWS to NACA, July 27, 1918 (NBS Box 13, INM).

[65] "War Work," p. 34.

make it impermeable to wind and moisture, and improve the flight characteristics of the plane. In the turmoil of designing an American plane and engine, the subject of dopes was somehow overlooked, and when late in 1917 the first acetate orders went out, its raw materials had already been commandeered by other Government agencies.

With acetate gone, nitrate (guncotton) dopes were used for a time, until Eastman Kodak provided a small supply of acetate from cuttings and scraps of nonflammable motion picture film. (Why the airplane program was left with cuttings and scraps is not recorded. True, the research came late in the war and remained in the experimental stage. Possibly, too, the supply of motion picture film was limited and was needed by the services and for the spate of propaganda films made for domestic consumption.) Meanwhile, the Bureau was testing scores of new solutions proposed as dope substitutes, establishing specifications for those that seemed to have some value, and making studies of their application to fabrics. Only a few "fire-proofed" nitrate dopes of the many so-called fire-resistant solutions submitted proved acceptable, and then only when the fabric itself was also fireproofed.[66]

American scientists never wholly overcame the problem—nor did anyone else. The need for fireproofing was real even though in aerial combat, tracer and incendiary bullets rarely ignited the fabric of planes. It was the engine of World War I planes that was most susceptible to fire. Occasionally a pilot was able to execute sideslipping maneuvers and keep the engine flames from igniting the fabric. Where that failed, the plane was consumed as it fell.

OPTICAL GLASS AND OPTICAL INSTRUMENTS

Although Dr. Stratton never actively took part in the optical research at the Bureau, his work with Michelson on light at the University of Chicago was the impulse for his years of personal direction of the optical division.[67] The men he brought in—Bates in polarimetry, Coblentz in radiometry Priest in colorimetry, Peters in interferometry, Meggers in spectroscopy—were topnotch, and he zealously followed with them every development in the field of optics both here and abroad. Yet as numerous as were the military applications of optics, it was a crisis in supply that shaped the principal wartime effort in optics at the Bureau.

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[66] "War Work," p. 56.

[67] Explaining the interferometer and its use in standardizing gage blocks to a congressional committee on one occasion, Stratton said that "interferometry is the field of measurement in which I am personally interested, and in which I was engaged when called to take charge of the bureau" (Hearings * * * 1924, Nov. 16, 1922, p. 191).

Stratton had long expressed concern over the foreign monopoly in high-grade optical glass and the fact that this country had to import every quality optical instrument it used. Because the glass for the optical systems of telescopes, microscopes, field glasses, navigation and surveying instruments, cameras and similar instruments was expensive to make and the market limited, American optical firms imported their quality glass and confined their manufacturing to spectacle glass, a product midway between optical and plate glass.[68] They had made little effort to learn for themselves German formulas and techniques and were content to have high-grade instruments manufactured abroad.[69] The war in Europe abruptly cut off the supply of both optical instruments and optical glass.

In the fall of 1914 Stratton ordered furnaces and apparatus for the Pittsburgh laboratory, where investigation of American clays and ceramics was already going on, and set it to work studying the manufacture of optical glass. A year later the Bureau began supplying its data to experimental optical glass plants organized at Bausch & Lomb, Keuffel & Esser, Pittsburgh Plate Glass and other firms that had been urged to take on this work. But development of good optical glass was a slow process, artisans in precision grinding were hard to find, and few outside the Bureau seemed to sense the emergency. When America entered the war in 1917 the industry had progressed little beyond the experimental stage.[70] In desperation, urgent appeals went out across the Nation begging private owners to lend their binoculars and field glasses, in whatever condition, to our military services.

Optical glass, a mixture of silica and chemicals melted in a clay pot, was highly susceptible to contamination from deterioration of the pot material under high heat. The initial problem of the Bureau was to find a suitable mixture of American clays as pot materials, capable of resisting the corrosive effect of fluid optical glass. The first satisfactory pot made was based on a

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[68] Spectacle glass came under scrutiny during the war, too, when the cost of eyeglasses skyrocketed. Secretary of War Newton D. Baker complained to Commerce, and Stratton was asked to investigate. The war had "nothing to do with the increase in prices," the manufacturers told Stratton. Their price on lenses was a few cents each and they had increased it less than 10 percent. But the jobbers had raised their profit by 25 to 33⅓ percent and retailers by 200 to 500 percent. Letter, Secretary of Commerce to Secretary of War, July 18, 1918, and attached correspondence (NBS Box 14, IPO).

[69] Quality optical glass, unlike glass for electric light bulbs, bottles, and window panes, must have a high degree of chemical homogeneity, freedom from physical imperfections, and be of varied compositions to insure a wide range of refractive index and dispersion. For its prewar status, see Science, 41, 788 (1915); George W. Morey, The Properties of Glass (New York; Reinhold, 1938), p. 26; Samuel R. Scholes, Modern Glass Practice (Chicago: Industrial Publications, 1946), p. 59.

[70] Robert M. Yerkes, ed., The New World of Science, p. 108; Secretary of Commerce correspondence, 1917, NARG 40, file 67009/43; MS, "Development of optical glass at the Bureau of Standards" (NBS Box 482, PA).

kaolin-clay mixture. After more than a year's work on this and other compositions, Dr. Bleininger produced a superior porcelain pot unlike any previously known in this country. Widely acknowledged in the industry as an original contribution to the technique of glass manufacture, it proved one of the Bureau's most notable accomplishments in the war effort.

Drawings and specifications of the potmaking equipment were furnished to the commercial glass companies, as were data on annealing, optical constants, polishing processes, and inspection tests and methods devised by the Bureau. Bleininger's crucible or melting pot and the glass data came none too soon, for in May 1918, as the shortage became critical the War Industries Board ordered an all-out effort to achieve large-scale manufacture of optical glass.[71]

The early glassmaking experiments at Pittsburgh were conducted with pots holding about 30 pounds of glass. Compositions and methods of treatment of the different kinds of optical glass were first studied in these 30-pound melts, with laboratory personnel from the optical firms and representatives of the Geophysical Laboratory of the Carnegie Institution in Washington present as observers. In the winter of 1916–17 a larger furnace holding a 1,000-pound pot was built, and in this was made the first large melt of commercial borosilicate, as well as successful melts of crown and prism glass. Altogether, eight types of glass were made during the war in Bureau furnaces, totaling 15,000 pounds, of which more than 3,000 pounds comprised first-grade binocular glass. Only efforts to make dense barium-crown glass of the type used for photographic lenses were not wholly successful, and work on this continued after the war.[72]

Late in 1918, after producing almost 300 melts of optical glass, the Pittsburgh glass plant was transferred to the new Kiln building, with 8 melting furnaces, going up on the Bureau grounds in Washington. The importance of the Bureau's war work on refractories and glassmaking assured continuance of this research all through the 1920's and 1930's, and during World War II glass production at the Bureau was again undertaken on a full-scale basis.

In addition to the exhaustive testing of optical glass samples produced in the Pittsburgh furnaces, the optical laboratories in Washington were on constant call to advise on the design, construction, and testing of almost every optical instrument made for the Signal Corps and for Army and Navy Ordnance. Special test devices had to be constructed and frequent factory conferences were necessary since many of the instruments were being

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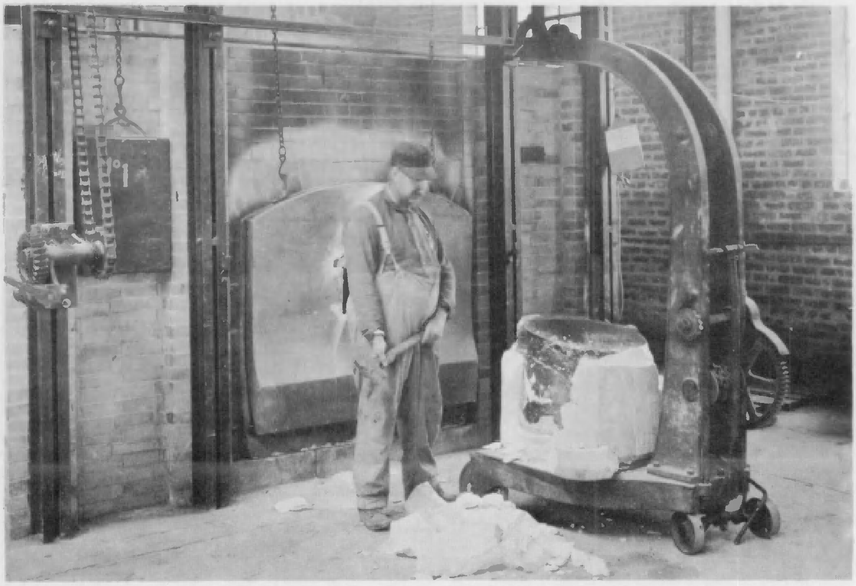
[71] The pot composition was described in NBS Annual Report 1919, p. 266. See also Clarkson, Industrial America in the World War, pp. 470–471; Crowell, America's Munitions, pp. 139–140, 577; A. V. Bleininger, "Recent developments in ceramics," Chem. Met. Eng. 19, 467 (1918).

[72] Redfield, With Congress and Cabinet, p. 209; "War Work," pp. 183–185.



After the optical glass mixture has gone through the melting process and solidified under slow cooling, the pot is broken away from the 1000-pound melt. The glass cannot be removed from the pot in a molten or plastic condition or bubbles and cords will form. Although the chemical composition of good optical glass had been mastered by World War I, a satisfactory pot material had not, and the special kaolin-clay mixture developed by the Bureau proved a real contribution to the industry.

manufactured in this country on a large scale for the first time. This was particularly true of binoculars, but also included periscopes, range finders, military and naval gun sights, bomb sights, and aviators' goggles. Important assistance was given as well in the manufacture of mil scales for military binoculars and in the development of the 37-mm gun sight, the panoramic machine gun sight, a new tank-gun sight, and a periscopic alidade.

The alidade, an angle-measuring device, illustrated how our armed services acquired some of their new optical instruments. The AEF sent back a French model, asking the Army Engineers to copy and supply it to our forces. The Bureau took it apart and from the data supplied, the Engineers prepared the blueprints for an instrument manufacturer. Samples of the American-made alidade then came back to the Bureau and with a few minor changes the device was approved for production.[73]

An interesting adaptation of peacetime optical research to wartime needs occurred in the case of military photography. Some years before the war, the spectroscopy section had carried out an extensive program of measur-

[73] "War Work," p. 188.

ing standard wavelengths of light, particularly in the spectra of neon, helium, and iron, by photographic means. Making these observations required a broad knowledge of the underlying complex elements of photography. It also drew attention to the fact that highly sensitive plates capable of photographing the wavelengths of red and infrared light could not be purchased commercially. Preparing their own plates, Bureau spectroscopists under Dr. Meggers made a systematic study of the spectra of some 50 of the chemical elements, and in 1917 began photographing stellar and solar spectra to determine their composition.

With the war, the spectroscopy section turned to military problems of aerial photography. By then physicists both here and abroad were using plates at least four times as sensitive and fast as the best commercial orthochromatic (sensitive to blue, green, and yellow) and panchromatic (sensitive to all colors) plates in use by the military. The Bureau phyicists were also using new dyes of British manufacture, devised to replace German aniline dyes, and following a series of experiments offered their adaptation of these dyes to the Air Service, for use in photographing battle terrain through haze and smoke and detecting military works under camouflage.

Extensive experiments with the red-sensitive plates were carried out at Langley Field in the spring and summer of 1918, but because of the fixed idea of the military that the Bureau plates were still in an experimental stage, they were never used overseas. Before the war ended, however, their practical use had been completely demonstrated, and with the design and construction of new photographic lenses for use with red light, the importance of red-sensitive plates in military photography was fully acknowledged.[74]

Bureau scientists also designed a new airplane camera using film instead of plates, and at the time of the armistice had under construction for Ordnance a special camera that photographed the inside of machine-gun barrels to determine their degree of deterioration—a piece of technology enormously important in gunmaking and maintenance.[75] Sharing its laboratory space, the Bureau provided facilities to the Engineers, the Geological Survey, and the Navy for camera and lens designing and testing and for camera mechanism testing by the Signal Corps. Among the guest scientists in the optical laboratories was Albert A. Michelson, Stratton's former superior at Chicago, who came on his first visit to the Bureau to work on new long-range binoculars he had devised for the Navy, and later returned to test the optics of the short-

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[74] "War Work," pp. 202–207; NBS Annual Report 1918, pp. 83–84; Annual Report 1919, pp. 115–118; letter, SWS to Capt. Edward J. Steichen, Air Service, SOS, France, Dec. 3, 1918 (NBS Box 14, IPO).

[75] "War Work," pp. 186–187; NBS Annual Report 1919, pp. 141–142.

base Michelson rangefinder, another instrument he had designed for the Navy.[76]

It was a time of crash programs, of improvisations, of hurried application of basic principles, of hastily contrived instruments and equipment. In optics as in other areas of research the Bureau worked in largely untried ground. Some of its efforts saw service, some came too late. The same experience befell the scientists and technicians in the nearby radio laboratories.

"NEW THINGS IN RADIO COMMUNICATION"

When the war came, the Bureau radio laboratories under Dellinger and Kolster, as well as the adjacent Navy radio laboratory and that operated by the Signal Corps, were still relatively small affairs and for the most part more concerned with basic radio phenomena than with their practical applications. How far behind other nations the United States was in radio communications became known when the French scientific mission that arrived in the spring of 1917 left with the Bureau some of the scientific apparatus in use overseas. Included was a great variety of radio equipment developed around the electron tube.

Although the electron or vacuum tube amplifier was the invention of Fessenden and De Forest in this country, its use was practically unknown to our military departments, which still used damped wave apparatus that limited them to code telegraph.[77] A decade of patent litigation centering around the vacuum tube had blunted the growth of radio here at home. (It happened again with color television in the 1950's and 1960's.) The French, on the other hand, with government control of rights to the vacuum tube, used it in all their radio apparatus, in wire telephony, and in their radio telephone.

Outraged by the stifling consequences of the litigation, Strattton exclaimed to Congress: "It is time we should be working out the new things in radio communication instead of depending on foreign countries for scientific developments." [78] But even the Bureau had been helpless as the experimental

[76] Letter, SWS to Chief, Navy Bureau of Ordnance, Aug. 8, 1918 (NBS Box 4, AGC). Report attached to letter, SWS to War Production Branch, Mar. 5, 1919 (NBS Box 15, IRG), also notes an optical striae investigation made by Michelson at the Bureau. See NBS S333 (Michelson, 1919).

[77] Southworth, Forty Years of Radio Research, p. 38; "War Work," p. 233.

[78] Hearings * * * 1919 (Jan. 25, 1918), p. 978. For an account of the litigation involving De Forest's audion tube, the British and American Marconi Companies' Fleming valve, the General Electric audion of 1913, and Western Electric's audion of 1917, see Schubert, The Electric Word, pp. 126–131.

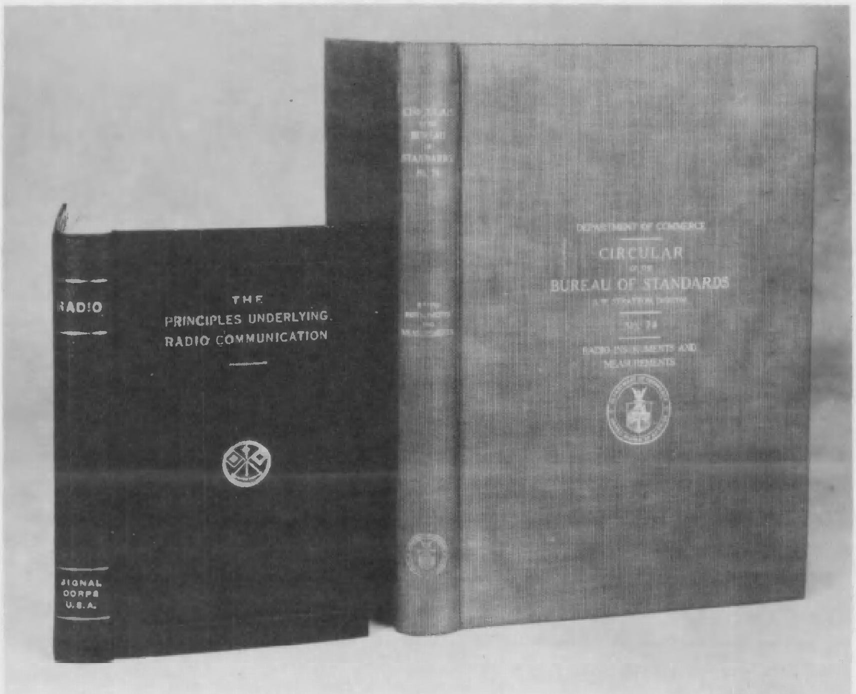
and commercial exploitation of the vacuum tube remained locked in the courts.

The impasse was broken on April 7, 1917, when by Presidential proclamation all commercial radio, comprising some 60 stations serving maritime commerce, was handed over to the Navy Department, and all other stations, amateur and privately owned, were closed down for the duration. The Navy, long anxious to secure better equipment for its ships, its coastal stations, and the radio chain it operated across the Pacific, immediately assumed all liability for patent infringements, and companies sprang up overnight to manufacture radio equipment, vying with the big three, General Electric, Westinghouse, and Western Electric, already in the field.

That event, together with the visit of the French commission and the requirements of the Army Signal Corps and the Navy, provided the major stimuli for the attack on the wartime radio problems facing this country: the training of technicians, civilian and military, in a complex and rapidly changing subject; the establishment of a high-powered transatlantic radio system (clearly of foremost importance not only for itself but in the event the enemy cut the telegraph cables) ; the development of low-powered radio equipment for battlefield communication; radio means for locating enemy radio stations, airplanes, ships, and submarines; equipment for communication with submarines when submerged; and portable radio apparatus.[79]

In the Navy laboratory at the Bureau, Dr. Austin, who in his long-distance transmission research had recently begun an investigation of the reenforcement of signals from the upper layer of the atmosphere, now took up the development of new radio apparatus for his service. In the Bureau laboratories the most immediate consideration was the training of thousands of men in radio communication for the Signal Corps to meet battlefield needs. To update available training material and set up better courses of radio instruction, a conference of university representatives was called at the Bureau in late December 1917. Following the conference, a Bureau group under Dr. Dellinger rushed preparation of a treatise on radio principles, measurements, and theory—subjects not covered by any publication then available—to supplement Signal Corps training pamphlets. Circular 74, "Radio instruments and measurements," with 318 pages of text, a bibliography, index, and 224 illustrations, came off the presses in March 1918, as a much needed reference book for radio instructors in the Army and Navy schools and the universities. It appeared later in hard covers as a commercial publication and its continued usefulness led the Bureau to issue a revised edition in 1924. Frequent reprints made this bible of radio engineers and amateurs available through the next two decades.

[79] "War Work," pp. 223–225.



Two famous books, on radio communication and on radio principles, theory, and measurements, were written in 1917–18, making widely available the unpublished results of radio research carried out in the Bureau laboratories.

Circular 74, on measurements, was a radio reference book, the first which based radio theory on straight alternating current theory, giving damped waves only minor and separate treatment. The volume on principles was an elementary textbook, originally designed to accompany Signal Corps radio apparatus issued in the field, but used for many years as both reference and textbook.

Soon after Circular 74 came out, the Signal Corps requested an elementary textbook for enlisted men, as background for its training pamphlets, to cover in nonmathematical language the fundamentals of electricity and dynamoelectric machinery, as well as radio circuits and apparatus. Six college faculty members were invited to the Bureau to work with the radio staff on the book. They completed the 355-page text of The Principles Underlying Radio Communication in just 3 months. (Because of its joint authorship, it did not appear as a Bureau publication.) Press difficulties prevented the Signal Corps from issuing the book until March 1919, and instead of the planned 50,000 only 6,000 copies were printed. Admired by Thomas Edison as "the greatest book on this subject that I have ever read," it was reprinted when Army and Navy schools and a number of colleges later adopted it as a standard radio textbook.[80]

From the beginning of hostilities, the Bureau and the military services were bombarded with ideas for using radio as a weapon of war. Most notable perhaps was Thomas Edison's proposal to establish a transmitting station near Ostend, in British-held Flanders, to interfere with radio communication between German submarines and their bases. The Bureau had to tell him that a single station probably would not be sufficient. And even if it were, interfering signals sent out from even that one station in Flanders might well spread along the whole of the Western Front and confuse all radio communication there.[81]

A more practicable approach to the U-boat menace seemed possible through Kolster's radio direction finder, still in the experimental stage when we entered the war.[82] With the incorporation of a French electron tube amplifier and a new coil aerial, replacing the former antenna, a more compact unit with greater range of usefulness at once became possible. It was seen not only as an aid to air and sea navigation but as a potential means of locating enemy radio sending apparatus and, therefore, the enemy himself, whether in the trenches, in the air, or under the sea. Essentially a simple rotating coil that detected transmitted radio waves and then narrowed down the direction from which they were sent, the improved direction finder under ideal conditions achieved a pinpointing accuracy of close to 1 percent.

One application of the radio direction finder, largely the work of Kolster's technical assistants, Willoughby and Lowell, appeared particularly significant. So far as was known, no navy had developed a radio system for use in submarines, in the belief that sea water could not be penetrated by radio waves.[83] Before its first underwater tests, the Bureau had determined that with exceedingly sensitive amplifiers the coil aerial of the finder might act as both a transmitting and receiving device. Next, the Bureau began underwater tests of the coil and found, surprisingly, the signals almost as strong as with the coil in the air. Experiments on cruising submarines followed, and in final tests off New London in June 1918, the apparatus picked

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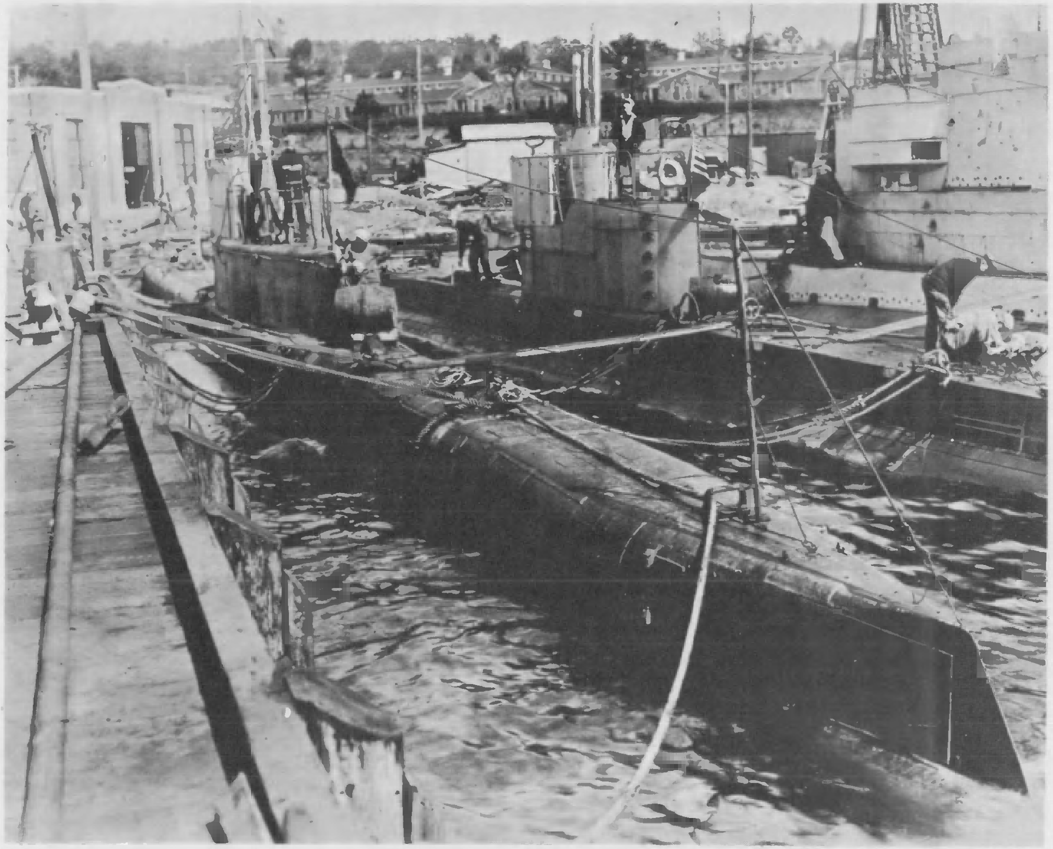
[80] See chap. III, p. 138. Southworth, Forty Years of Radio Research, pp. 36–38; "War Work," pp. 227–229.

Still another Signal Corps publication prepared at the Bureau was Vacuum Tubes: Theory and Use, a compilation of all available information on the subject for the use of Army and Navy radio engineers. NBS Annual Report 1918, p. 47.

[81] Letter, SWS to Thomas Edison, Dec. 7, 1917 (NBS Box 10, IEW).

[82] The basic idea of the direction finder was an Italian invention, to which the British secured rights in 1912. Kolster's invention appears to have been an independent discovery and sufficiently different to raise no question of patent infringement. Schubert, The Electric Word, pp. 139–140; conversation with Percival D. Lowell, Mar. 4, 1963.

[83] War Work, p. 231.



The submarine at New London, Conn., equipped by the Bureau with special antenna for underwater radio reception and transmission.

In place of the large antenna used in his original direction finder, Kolster found that with the more sensitive amplifiers that had become available, a simple coil aerial was equally effective for receiving and transmitting radio waves.

Neither here nor abroad had navies developed a successful radio system for underwater use when late in 1917 one of Kolster's direction finder coils was tested, first under water, then in a submerged submarine, and in both instances picked up clear signals from as far away as Europe and our own west coast.

up clear signals transmitted from Germany, from Paris, Rome, and California. Still later tests proved it possible to transmit as well as receive radio messages in a submerged submarine, although the sending range, about 12 miles, was short.[84]

Experiments with the radio direction finder as an aid in aviation began in 1918 soon after the Post Office Department started a daily airmail service between New York and Washington. Night flights of the mail were still 3 years away, but presenting an immediate and comparable hazard was the problem of flying in daytime rain and fog. The pilot's compass guided him toward his landing field but gave him no indication when he was over it. At the request of the Post Office, the Bureau took up the problem and made two adaptations of the direction finder that answered it, one employing magnetic induction, the other a radiofrequency current. Either of these enabled the pilot to hear a signal when he was directly over the field. A crude device and effective only at altitudes up to a mile, it was nevertheless the forerunner of modern instrument landing techniques.[85]

No invention factory, the Bureau was drawn into these and other experiments as the organization best equipped to handle such problems for other Government agencies.[86] In radio research, its mission of providing and maintaining basic measurements was better exemplified in the constant and careful reassessments made of its standards of inductance and capacitance on which standards of radiofrequency or wavelength were based,

[84] War Work, pp. 229–232.

[85] Letter, SWS to Postmaster General, Nov. 29, 1919 (NBS Box 10, IEW); "War Work," pp. 232–233; NBS Annual Report 1919, pp. 66–67.

[86] One of the prime functions of the Bureau, the solution of problems relating to measurement, inevitably led to a number of patentable materials, processes, and products. From about 1910 on, members of the Bureau were granted a steady stream of patents for new or improved instruments and devices, including a new type of thermopile by Coblentz (1913), Kolster's decremeter (1913), Schlink's improvements in weighing scales (1916), Kolster's radio direction finder (1916), Whittemore's element for airfoils (1918), Willoughby and Lowell's submarine radio (1919), Bleininger's porcelain for spark plugs (1919), Priest's inferential dilatometer (1919), Ingberg's fire-resistant column cap (1920), and Emley's plastic gypsum (1920). A more complete list appears in NBS Box 71, AB-2105.

Although other Government agencies permitted and even encouraged their employees to take out patents in their own names and exploit them, under Stratton it was an unwritten but inviolable policy of the Bureau that patents of its employees were to be assigned to the use of the Government and the free use of the public. (Letter, SWS to Commissioner, Bureau of Navigation, May 21, 1913, and letter, SWS to W. D. Shoemaker, Patent Office, Aug. 28, 1919, in NBS Box 4, AGP.) No evidence appears in Bureau records that industry ever objected to this policy, but Bureau inventors were not always happy with it and on occasion rebelled. See Coblentz, From the Life of a Researcher (New York: Philosophical Library, 1951), pp. 141–143, and footnote ch. VI, pp. 348–349.

the standards themselves "handled with a care and reverence that was comparable with that given to the prototype platinum-iridium standard meter bar." [87] Basic too was the Bureau work on the new electron or vacuum tube.

With patent litigation suspended, radio manufacturers turned out large numbers of these tubes as generators, detectors, amplifiers, and modulators of radio waves and other electrical currents. (Some of the early tubes were as large as the wall telephones then in use.) Most of them went into the radio communication apparatus constructed in the Signal Corps and Navy radio laboratories at the Bureau and produced in quantity for these services by the electrical industry.[88] The Bureau measured the characteristics of both experimental and production tubes, devised test methods and apparatus, standardized certain types of tubes, and made studies of their behavior in a variety of circuits.[89]

Of special importance in its work with vacuum tubes were the first Bureau studies of such phenomena as the effects of diurnal fluctuations, solar activity, and atmospheric electricity on radio communication. Out of this work in the postwar years came wholly new concepts of the dimensions of radio, as well as new standards of radio measurements.[90]

Wartime research on the electron tube, which had previously been little more than an artifact of the radio experimenters in this country, made possible reliable long-distance wire telephony, as well as speech communication between ground stations and airplanes. Incorporating the vacuum tube in the direction finder made it a convenient and portable apparatus that was to prove as useful in detecting transmitting stations violating radio laws as it was in guiding planes and ships through fog. In its role as an amplifier, the vacuum tube permitted for the first time very small antennas, and by greatly extending the range of radio communication ushered in the age of radio.

That age did not, as might have been expected, begin with the armistice. It was delayed first by the threat of Government ownership and then by renewal of the patent wars of the radio industry. Under the widely held

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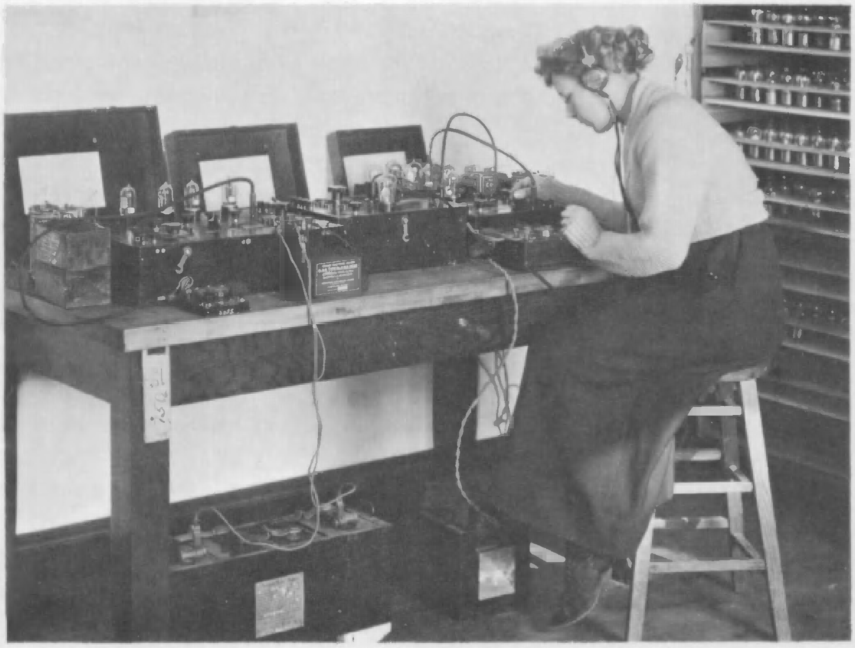
[87] Southword, Forty Years of Radio Research, p. 34.

[88] For the wartime Navy research at the Bureau in long-distance communication, see report of L. W. Austin in J. Franklin Inst. 193, 437 (1922), and NBS Letter Circular (LC) 194 (Mar. 10, 1926).

[89] A discovery made at that time in the idiosyncrasies in vacuum tubes, since known as the "Miller effect," was first published in John F. Miller's "Dependence of the input impedance of a three-electrode vacuum tube upon the load in the plate circuit" (S351, 1919). See also NBS Annual Report 1919, pp. 65–66, and F. Langford Smith, ed., The Radiotron Designer's Handbook (Sydney, Australia: Wireless Press, 3d ed., 1940), pp. 46–48.

[90] "War Work," pp. 233–242.



The use of the three-electrode (triode) electron tube was practically unknown to our military forces prior to 1917, and all of their apparatus was of the damped-wave type. The Bureau began testing electron tubes, as shown here, a month after we entered the war, and reported testing 467 of them up to mid-1919.

assumption that radio was essentially an instrument of navigation and of national defense, and therefore must be under Government control, as it was in Europe, bills to that end were offered in Congress on behalf of the Navy Department in January 1917 and again late in 1918. On both occasions Congress, ever fearful of outright Government control or ownership of anything, tabled the proposals.[91]

Rebuffed, yet concerned for the development of its radio system, the Navy Department urged General Electric, largest of the radio manufacturers, to buy out the British-backed Marconi Co. whose commercial radio system had been taken over by the Navy in 1917 and was, with the end of the war, to be returned. The result was the formation in October 1919 of a General Electric subsidiary, the Radio Corporation of America, which at one stroke became owner of virtually all the commercial high-power radio facilities in the country.[92]

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[91] Secretary of Commerce Redfield and Dr. Stratton both favored Government control, either under the Navy or, better, under Commerce. See Hearings * * * 1920 (Dec. 12, 1918), p. 946, and correspondence in NBS Box 10, IEW 1918–20.

[92] W. Rupert Maclaurin, Invention and Innovation in the Radio Industry (New York: Macmillan, 1949), p. 99.

But the moratorium on patent litigation also ended with the war, and since no one had an important infringement-free radio patent, the expectations of commercial radio were checked. Except for laboratory experimentation, the wartime work on vacuum tubes, radio circuits, and transmission apparatus remained out of reach to all. Until that impasse was breached in 1921, no radio manufacturer could safely make anything but crystal sets for the public. The Bureau continued its research and waited.[93]

FROM GAGES TO GAS MASKS

The mass production of guns, ammunition and other ordnance material, with components made in almost 8,000 plants across the country, reached a scale in World War I never before attempted in any machined product. The manufacture of interchangeable parts and components in widely separated factories depended upon the accuracy of hundreds of thousands of gages, and of the master gages on which they were based. Construction of a single round of artillery ammunition, for example, required gaging of 80 dimensions, necessitating the use of over 500 different gages. To standardize these shop gages required 180 master gages.[94]

The work of standardizing and testing master gages, begun under an urgent deficiency appropriation of June 1917, soon outstripped the facilities Stratton had set up 2 years before at the Bureau, and branches were established in New York, in Cleveland, and at Bridgeport. The 4 laboratories handled over 60,000 gages used in making America's munitions.[95] The magazine Science was to say that "The national provision for master-gauge standardization was one of the most important contributions of the war." [96]

At the height of its activity the Bureau gage section numbered 225 engineers, physicists, master gage experts, inspectors, toolmakers, technical assistants, and administrative aides. Besides testing and calibrating gages, the section trained gage inspectors for Ordnance plants, Navy yards, arsenals, and commercial manufacturers. It also carried out an extensive salvage

[93] Memo, SWS for Secretary of Commerce, Sept. 21, 1921 (NBS Box 10, IEW).

[94] Crowell, America's Munitions, pp. 25, 124–125. Including the gages used by Government inspectors, almost 800 gages were necessary in the manufacture of a single complete round.

[95] These comprised plain gages (plain plug, snap, and ring gages), profile gages (templets, chamber and fixture gages), and screw-thread gages. Originally set up in the Stucco building (erected early in 1918 for the testing of building materials), the gage laboratory moved to larger quarters in Northwest building later that year. Of more than $4 million spent by the War Department for gages in 1917–18, Stratton reported, over $550,000 came to the Bureau (Hearings * * * 1921, Jan. 2, 1920, pp. 1583–1584).

[96] "The work of the Bureau of Standards during 1918," Science 39–40 (1919).

program as large numbers of gages in Ordnance factories became obsolete when designs were changed or wore out. The Bureau shops rebuilt nearly a thousand gages for serviceable use again and constructed almost 500 new master and inspection gages as replacements.[97]

The invention that perhaps contributed most to the manufacture of interchangeable parts was the famous set of precision gage blocks made by the Swedish engineer Carl Edvard Johannson in 1904. For many years these were the only satisfactory standards of their kind available for the manufacture and inspection of closely machined parts. Prior to the war their sole source was Sweden, and so exquisite was their workmanship that production never kept up with demand.[98] When this country began tooling up, they were not to be had at any price.

Late in 1917 an inventor, William E. Hoke, came to the Bureau proposing a method for the mechanical manufacture of precision gage blocks that promised to be near equivalents of the Swedish blocks. Persuaded that their manufacture was feasible, the Bureau obtained the sum of $375,000 from the Ordnance Department to make them and after several months produced a satisfactory set of the blocks. Altogether, 50 sets were made, each comprising 81 blocks, ranging from 0.05 inch to 4 inches, and each block accurate to within 0.000005 inch. Their value, apart from the fact that nothing comparable could be had, Stratton declared, far exceeded the amount of the allotment made for their production.[99]

Allied with the gage work was that of the National Screw Thread Commission, established by Congress in July 1918 with nine members from the War, Navy, and Commerce Departments, the American Society of Mechanical Engineers, and the Society of Automotive Engineers, under the chairmanship of Dr. Stratton. The Commission sought to simplify the variety of threads, sizes, types, and systems then prevailing in industry, and standardize those having the most extensive use and utility. Among other things, standardization of threads (and hence interchangeability) would facilitate repair or replacement of machines and their parts, as well as of all machine-made threaded products from nuts and bolts to hose couplings.

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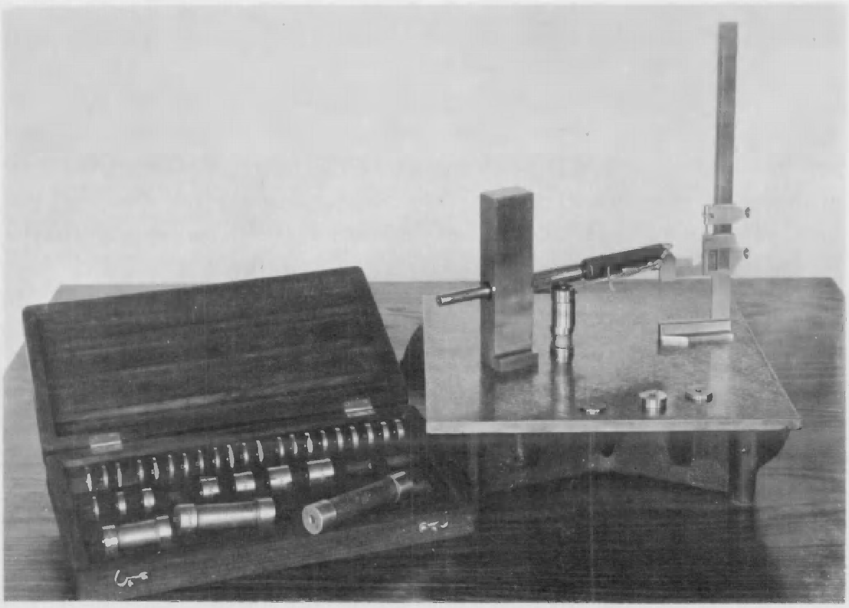
[97] "War Work," pp. 116–117; report, Van Keuren, "Progress of munition gage testing at the Bureau of Standards" [ca. Sept. 1918], in NBS Historical File.

[98] Joseph V. Woodworth, Gages and Gaging Systems (New York: Hill, 1908), p. 229, described the first set of Johannson's blocks seen in this country. Combinations of the blocks, ranging in thickness from 0.1001 to 4 inches, made possible at least 80,000 sizes. For Johannson's description of the blocks, see NBS Standards Yearbook, 1931, pp. 14–15. (Johannson was then an engineer with the Ford Motor Co.)

[99] Hearings * * * 1920 (Dec. 12, 1918), p. 952; letter, SWS to Ch, Inventions Section WD, Dec. 23, 1918 (NBS Box 19, IWG); NBS Annual Report 1919, pp. 37, 148–149; interview with Irvin H. Fullmer, Mar. 23, 1962.



The Hoke precision gage blocks used in the manufacture of closely machined parts, shown here being used to determine the dimension of a limit gage. Any desired dimension can be obtained by combining various sizes of blocks, as in the three used here to test the limit gage in the jig.

It was an almost impossible task to undertake in the midst of war. Congress twice extended the term of the Commission, to 1920 and then to 1927, in order that it might implement its plans to "reduce the variety of screw threads in general use, facilitate manufacture in case of war, make the best use of labor in our industries in time of peace, increase the safety of travel by rail, steamship, and aeroplane, and in general * * * increase the dependability of all mechanisms." [100] It would take the coming of another war before progress became visible.

Besides its work on threads and gages and the extensive investigations in substitute materials, in aeronautics, optical glass, and radio, the Bureau responded to calls for help with literally hundreds of other wartime problems submitted by industry and the sciences. Only mention can be made of the almost continuous testing carried out on protective coatings, from experiments in electroplating techniques to tests of bituminous materials, varnishes, enamels, fire-retarding paints, and special paints for projectiles.[101] The Bureau established safety standards for military plants and factories. It

[100] NBS M42, "Progress report of the National Screw Thread Commission" (1921), p. 5.
[101] "War Work," pp. 66–67, 208–220.

investigated the protective properties of goggles and glasses for laboratory workers and those used by oxyacetylene cutters and welders against injurious ultraviolet and infrared radiations.[102]

It made studies in the use of radium and other self-luminous materials for illuminating aircraft instruments, gunsights, marching compasses, watches, and navigation instruments. In addition, almost 500 preparations of radium, for use in surgery and dermatology, were measured and certified in the Bureau's radium laboratory. An investigation of X-ray protection in this laboratory for the Surgeon General's Office demonstrated that many of even the most expensive X-ray shields then on the market were practically worthless. And with the X-ray apparatus acquired for these studies, the Bureau also began its preliminary study of techniques for the radiographic detection of flaws in aluminum and steel, which were to succeed where in many cases magnetic testing failed.[103]

The Bureau developed an improved blasting machine for the Corps of Engineers, worked on rockets and illuminating shells with the Trench Warfare Section of Ordnance, and helped design signal lamps for daylight transmission of messages in the trenches or between planes in flight.[104] The colorimetrists and photometrists of the Bureau supplied scientific data for a high-priority searchlight investigation made by the Engineers. Dr. Harvey L. Curtis spent much of the war devising and operating his complex electrical circuits for measuring velocity and other ballistic characteristics of projectiles for the Navy.[105]

Investigations of sound-ranging and sound-detecting equipment, for locating distant or concealed enemy guns, began soon after the French mission brought to this country some of the apparatus in use overseas. Designing and constructing improved sound-ranging apparatus, as well as geophones and seismicrophones, to detect enemy mining operations in the trenches, and special microphones for the detecting of underwater sounds, occupied the Bureau's electrolysis (sic) section until well after the armistice.[106] The only death of a Bureau staff member on the battlefield occurred in this group. Dr. Ernest E. Weibel, who with Dr. Eckhardt and Burton McCollum made important developments in a new sound-ranging device, entered the Army as a captain in the spring of 1918 in order to take the equipment overseas and test it in the trenches in the British sector near Ypres. In a mustard-gas

[102] "War Work," pp. 261–263, 246; NBS Annual Report 1918, p. 103.

[103] "War Work," pp. 251–255, 298–299; NBS Annual Report 1918, p. 52; Annual Report 1919, p. 74.

[104] "War Work," pp. 107–112, 124–127.

[105] Crowell, America's Munitions, pp. 389–391; "War Work," pp. 263–265; NBS Annual Report 1918, p. 41; Curtis, Recollections of a Scientist, pp. 39–51.

[106] Crowell, America's Munitions, pp. 384–387; "War Work," pp. 265–271; NBS Annual Report 1918, pp. 67, 104–105.

attack on that front in April he was badly gassed and died of complications several weeks later.[107]

Almost the whole of the legacy of science and technology that seemed so rich in promise at the turn of the century was, in that holocaust in Europe, reworked into weapons and agents of war. None was more frightening than the chemical poisons first introduced on the battlefield in 1915. Although it is difficult to believe, America entered the war 2 years later knowing little or nothing about the gas war in Europe. The Bureau first encountered its challenges when a special mission arrived with models of the protective gas masks then in use in France. Besides its investigations for American gas masks, the Bureau also worked with the Bureau of Mines, the Chemical Warfare Service, the Geophysical Laboratory, and the universities on a number of tests and experiments preliminary to this country's production of war gases and smokes.[108]

Two new gases were introduced in the field by the Germans as the AEF arrived in France in the summer of 1917. The first was mustard gas, for which no satisfactory defense was ever devised, the other, diphenylchloroarsine, a sneeze gas. The arsenical sneeze gas—actually not a gas but an irritant smoke—even in minute quantities readily penetrated all gas masks then in use, producing uncontrollable coughing and sneezing, and forced removal of the mask, to expose its wearer to the lethal gases that were fired simultaneously with the sneeze gas.[109]

In the Bureau paper mill and at a commercial mill a group under Dr. Philip V. Wells made numerous special crepe paper filters to prevent mask penetration of the smokes, testing them in a gas chamber erected on the grounds. But the filter, added to others already in the mask, so increased the difficulty of breathing while wearing the mask as nearly to immobilze the soldier. As a result, neither this country nor the Allies produced more than a handful of cannisters incorporating this paper, and sneeze gas casualties continued high to the end of the war.[110]

Hardly a day passed during the war years but a new problem in detection or a solution to an old one was presented to the Bureau. None

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[107] Redfield, With Congress and Cabinet, pp. 222–223. Lt. Arthur J. Fecht, member of the Bureau with Weibel, survived the gassing and served in the sound-ranging section of the 29th Engineers to the end of the war. Interview with Dr. Silsbee, Nov. 27, 1962.

[108] Crowell, America's Munitions, p. 405; NBS Annual Report 1918, pp. 104, 159; Annual Report 1919, p. 149.

[109] Studies of chemical substances in suspension were carried out in the Bureau's dispersoid section set up in the optical division.

[110] Letter W. K. Lewis, Research Division, CWS, to SWS, July 31, 1918 (NBS Box 6, IC); "War Work," pp. 72, 199–200. Almost a third of AEF battle casualties resulted from gas, most of them from mustard gas or phosgene, following concentrations of sneeze gas. See Col. H. L. Gilchrist, A Comparative Study of World War Casualties From Gas and Other Weapons (Washington, D.C., 1931), p. 19.

certainly exercised the scientific and inventive talents of the Nation more when we entered the war than did the menace of the U-boat. Submarine detection was widely held to be "the most pressing of all problems" that fateful spring as month by month the toll of merchant tonnage sent to the bottom steadily rose. It was estimated that for a time one-quarter of the leading physicists in this country were working on the submarine problem, and Edison's proposal to interrupt German submarine radio communication was but one of thousands of solutions suggested.[111] As obvious aids in sub hunting, and most capable of rapid development, the National Research Council urged the Bureau to devise special goggles, colored lenses, and special binoculars for better visual detection of submarines and their periscopes. But before these and more complicated means of detection got beyond the experimental stage, the convoy system with destroyer escort had been inaugurated and shipping losses began to abate.[112]

As pressing as enemy submarine detection was detecting the presence of dangerously combustible gases, hydrogen in particular, in our own submarines. Elmer R. Weaver of the gas chemistry section pioneered the development of thermal-conductivity measurements for the detection and analysis of such gases that later became the basis for a multimillion-dollar instrument company.[113]

Thermopiles or bolometers, for the detection of ships and planes by the radiation of heat from the smokestacks and exhausts, and electrical inductance devices, for detection of metallic mines laid by the enemy, were endlessly tested. None proved practical. Out of the work, however, came a device employing the thermopile principle that made it possible to send out infrared rays as signals without fear of detection. The Bureau felt it might have far-reaching applications, since these signals, unlike radio signals at the time, could be directed and could be operated without interference.[114] The device was a forerunner of the World War II snooperscope,

[111] Interview with Dr. Dellinger, Jan. 26, 1962. Even Dr. Stratton offered a device, based on a series of wire hawsers suspended from ships' sides that would offer sufficient resistance to deflect torpedoes from their course. Letter, SWS to Ch, Bur. Const. and Repair, Navy Department, May 23, 1917 (NBS Box 11, IG).

[112] "War Work," p. 273. Some of the "target-finding torpedoes," one-man submarines, and electrical devices suggested to the Bureau for locating or destroying U-boats, often reached, Dr. Rosa said, into the realm of superscience. See correspondence in NBS Box 7.

[113] S334, "New forms of instruments for showing the presence and amount of combustile gases in the air" (Weaver and Weibel, 1919); T249, "Thermal-conductivity method for the analysis of gases" (Palmer and Weaver, 1924); Science, 126, 161 (1957).

[114] "War Work," pp. 133–139, 247; NBS Annual Report 1918, p. 146; letter, Millikan, Chief of R&D Division, NRC to SWS, Jan. 25, 1918 (NBS Box 14, IPR).

Dr. Goddard obtained his first rocket patent in 1914, in 1919 stated the principle of multistage rockets, and in the next decade developed liquid fuels and gyroscopic stabilizers for his rockets. His recoilless launcher demonstrated for the Bureau in 1918 fired a two-foot-long powder-loaded rocket.

The historic liquid-fueled rocket of the 1920's, pictured above, rose only 41 feet. With stabilization and better fuel the rocket flew 7,500 feet up just a decade later. Goddard's interest was not in weaponry but in methods of raising recording apparatus beyond the range of sounding balloons, in order to explore the upper atmosphere.

which was to detect reflections from infrared light projected by the scope itself.

At least two inventions that came to the Bureau in World War I proved to be 20 years ahead of their time. Late in 1916, Dr. Robert H. Goddard, a physics professor at Clark University, Worcester, Mass., went to Dr. C. G. Abbot, Secretary of the Smithsonian and head of the Astrophysical Laboratory, with an idea for a rocket device theoretically capable of firing shells "far outdistancing rifled cannon."

The principle of the rocket was of course centuries old, and in modern times its "red glare" had illuminated the bombardment of Fort McHenry, in the port of Baltimore. By increasing its thermodynamic efficiency and incorporating new power principles, Goddard believed he had found a way to control and enhance the flight characteristics of the rocket. Dr. Abbot agreed and called in Dr. Edgar Buckingham, the aerodynamics specialist at the Bureau. After studying Goddard's data they concurred on "the probable great military value of this rocket" and recommended that the Bureau assign $5,000 of its Signal Corps funds for development.

By January 1918 two models of Goddard's rocket gun had been designed, one with a potential range of 7 miles, the other of 120 miles. Buckingham reported that a working model of the former, preliminary to large-scale production, might be readied within 3 months if the work was pushed, and Stratton, with Abbot's accord, assigned another $10,000 for its construction. Goddard, meanwhile, had designed still other rocket weapons: a launching device for firing a sequence of rockets, a rocket trench mortar, and a "hand-supported recoilless gun"—prototype of the bazooka—capable of firing shells from a 5½-foot tube for distances of 400 to 700 yards.

Reports of the first tests of the rocket gun in July 1918 were good, but Dr. Stratton's efforts to find scientists and technicians through the Smithsonian to assist Goddard with further development were unavailing. Other wartime projects, with more immediate prospects of utilization, occupied every trained man in sight.[115] Goddard's project was shelved.

Destined for the next war too was the automatic rifle invented by John C. Garand. Originally submitted to Thomas Edison's Naval Consulting Board, the model was referred to Army Ordnance who sent it to the Bureau "to look over" in the summer of 1918. As received, it was "exceedingly crude and inoperative," Stratton said later, but its conception was sound, it had been made by "an excellent mechanician," and Stratton himself took personal charge of its development. After more than 6 months of work in the Bureau shops, the rifle was successfully fired. At that point litigation over the patent rights arose and with the war over the War Department lost interest. The Bureau returned the rifle to Mr. Garand.[116]

Day-to-day life at the Bureau during the war was hectic and dominated by a sense of urgency, but the brevity of this country's involvement and the distance from the battlefield prevented rise of the tensions that were to mark life in the Second World War. Except for the hush-hush designing of the Liberty engine, of Dr. Briggs' stable-zenith device for the Navy (to synchronize the training of big guns, independent of the pitch and roll of the ship), and of some aspects of sound-ranging apparatus, the Bureau was concerned with few classified projects. Apart from observing routine security measures, the Bureau staff and visitors came and went with a minimum of surveillance.

Although the Bureau had an officer of the day and a watch, the absence of vigilance was illustrated in an unscheduled visit made by the President and Mrs. Wilson, accompanied by Secretary Redfield, out Connecticut Avenue one Sunday afternoon to see the novel all-metal airplane sent to the Bureau for structural tests. The doors of West building where it sat were locked,

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[115] Letter, C. G. Abbott to SWS, July 25, 1918, and attached correspondence (NBS Box 10, IG). See Goddard's classic monograph on rockets, "A method of reaching extreme altitudes," Smithsonian Miscellaneous Collections (Publ. 2540), 71, 1–69 (1919).

[116] Memo, SWS to Secretary of Commerce, Mar. 25, 1921, and attached correspondence (NBS Box 12, IN).

but the Secretary found an unfastened window and all three climbed in to see the plane.[117]

And the Bureau found time to play. An avid reader of detective and mystery novels, the President one morning sent a messenger to the Bureau with an envelope bearing his seal. He had read the night before that such a letter could be opened and resealed without any sign of tampering. Could the Bureau do it too? A day later the President had his sealed letter back, apparently intact. Inside was a note and the lead disks from which the fraudulent seal replacing his seal had been made overnight.[118]

THE BUREAU AND THE METRIC SYSTEM

The war not only forwarded the Bureau's efforts to induce American industry to accept scientific measurements and methods in its operations; it also for a time brought hope that its long endeavor to secure general adoption of the metric system in this country might at last succeed. To its proponents the simplicity of the metric system in common measures and its advantages in scientific mensuration were overwhelming; to its opponents the cost to industry of conversion and the inconvenience to the public seemed insuperable. For years, a band of ardent antimetricists, supported by representatives of engineering and textile interests and by a merchant-minded Congress had repeatedly defeated metric legislation. Their success convinced Dr. Strattton that only through education of the public might sufficient pressure be generated to sway the lawmakers. The war offered an unexpected opportunity to further that education.

On January 2, 1918, a War Department General Order announced that the General Staff of the AEF in France had adopted the metric system and that guns, munitions, and certain other materials produced in this country and destined for the AEF would conform to metric measurements:

> The metric system has been adopted for use in France for all firing data for artillery and machine guns, in the preparation of operation orders, and in map construction. Artillery and machine-gun material intended for service abroad is being graduated accordingly. Instruction in the metric system will be given to all concerned.[119]

Alerted by the War Department, the Bureau at once ordered reprints of a descriptive pamphlet of the international metric system and of a large graphic wall chart derived from this pamphlet, both published by the Bureau

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[117] Redfield, With Congress and Cabinet, pp. 98–99.

[118] Letter, Secretary of Commerce to President Wilson, Jan. 26, 1918 (NBS Box 10, IG).

[119] War Department G.O. 1, Jan. 2, 1918, was based on AEF G.O. 65, Nov. 21, 1917.

some years earlier.[120] A circular prepared in 1914, "Units of weights and measures: definitions and tables of equivalents," went to press again, as well as a 30 cm (12-inch) comparison scale, printed on paper, that permitted direct visual translation from centimeters and millimeters to inches and fractions of the inch. Large numbers of each of these were soon on the way to the technical services of the military here and abroad for instruction purposes.[121]

The most widely distributed metric aid was a soldier's manual, especially prepared at War Department request shortly after the general order appeared. A 16-page booklet, precisely 10 by 15 cm in size, small enough to fit the pocket, and issued as NBS Miscellaneous Publication No. 21 was pointedly entitled: "Metric manual for soldiers—The soldier's primer of the metric system—An international decimal system of weights and measures adopted as the legal standard by France and thirty-three other nations, and in world-wide use."

The manual described the rapid wartime progress of the metric system, particularly in industry, and its "necessity for efficiency in warfare." It offered graphic examples of the units, showing the length of the meter in terms of the soldier's 1903 or 1917 rifle, cited dimensions of other objects familiar to the average soldier, and included a sketch of the origin of the metric system, brief tables of equivalents, and a glossary. After printing and distributing over 100,000 copies for military personnel here and abroad, the plates were made available to the Army and Navy for printing special editions.[122] With the American armies indoctrinated and a considerable segment of American industry working in metrics, the long-deferred legislation seemed at last in sight.

The interest of the Bureau in promoting the metric system went back to the act of 1866 that legalized its use in this country and the subsequent ratification of the Metric Convention in 1878, making the United States party to the creation and support of the International Bureau of Weights and Measures. Yet legislation to put the metric system into general and commercial use had not followed. Despite our decimal system of coinage, the fact that our common measures derived from the meter and kilogram, that almost all scientific measurement was based on the metric system, and that it was the only system of weights and measures specifically legalized by the U.S. Congress, opposition had arisen at once and could not be overcome.

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[120] NBS M2, "The international metric system of weights and measures" (1906); M3 (chart, 1908). Over 10,000 copies of the M2 had been distributed since 1906 and 22,000 copies of M3 between 1908 and 1915.

[121] Between 1915 and 1917, 10,500 copies of NBS C47 were printed; another 15,000 were issued in 1918. For printing data, see Annual Reports, Bureau of Publications, Department of Commerce.

[122] "War Work," pp. 220–221.

Beyond all practical considerations—and they were many but not insuperable—the opposition appeared bound as much by emotional principles as by practical ones: the common measures were soundly Anglo-Saxon in origin; they had mystic biblical connotations; above all, they were a kind of badge of our isolation from the affairs of Europe.[123]

The leading advocates of the metric system were of course the scientists and scientific institutions of this country. Three times at the turn of the century, in 1896, 1901, and 1903, they had mobilized to support metric legislation introduced in Congress, only to see it fail.[124] During the hearings in 1900 that led to the establishment of the National Bureau of Standards, the subject of metric legislation came up but fortunately was not pressed. As Dr. Stratton confessed not long after, had Congress known that the proposed bureau was favorable to the adoption of the metric system, a great many there would have opposed its establishment.[125]

Evidence of Bureau interest in the metric system—and perhaps as a demonstration of its application in the construction industry—appeared in the seeming irregular dimensions (that is, in terms of feet and yards) of North and South buildings and their laboratories, which resulted from their computation in metrics.[126] Regrettably, no correspondence has been found to indicate the reaction of either the architects or the builders to fitting conventional materials to unaccustomed dimensions.

From its very beginning, the Bureau took an active part in supporting metric legislation. It secured the cooperation of those who had assisted in

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[123] Two of the most dedicated of the antimetricists in the early century were Frederick A. Halsey and Samuel Dale, spokesmen for the textile industry and authors of one of the ablest of the antimetric books, The Metric Fallacy (New York: Van Nostrand, 1904).

For the considerable correspondence of Samuel Dale with the Bureau in the period 1904–23, see NBS Boxes 20, 21, 55, 58. Typical of the temper of antimetricists was the remark of Samuel Russell, clerk to Senator William H. King of Utah, who wrote in an 8-page letter on the subject: "Metricitis, like socialism and Christian Science, is a mental Aberration" (letter to Secretary of Commerce Hoover, Apr. 8, 1921, NBS Box 20, MS).

[124] Letter, SWS to Secretary of Commerce and Labor, Apr. 4, 1904 (NBS Box 21, MS). See also Hearings before Committee on Coinage, Weights, and Measures, Jan. 30, 1896 (L/C: QC91.U46), and Annual Report, Secretary of the Treasury, 1899, p. lxxvii.

A good account of early metric legislative efforts appears in William Hallock and Herbert T. Wade, The Evolution of Weights and Measures and the Metric System (New York: Macmillan, 1906), pp. 133–134. Still the most authoritative general work available on weights and measures, it devoted more than half its 300 pages to the origin, development, and uses of the metric system.

[125] Hearings before the Committee on Coinage, Weights, and Measures, May 3, 1900, pp. 7–8; letter, SWS to E. L. Corthell, Minister of Public Works, Buenos Aires, Argentina, Aug. 16, 1901 (NBS Box 21, MS).

[126] See Rosa, "Plans of the new buildings * * *," Science, 17, 137 (1903); Coblentz, From the Life of a Researcher, p. 131.

establishing the Bureau and it participated in the hearings in the House and Senate. On one occasion, early in 1902, Dr. Stratton spoke before a congressional committee for over an hour on behalf of a metric bill then under consideration.[127]

Altogether, nine measures relating to the metric system or to some other "decimal" system were introduced in Congress in the first decade of the century, but even with the strong support of such international luminaries as Lord Kelvin and Alexander Graham Bell, none could be enacted.[128] Although Dr. Stratton participated in every metric hearing in that decade and the next, he did not always support the measures proposed. Some he felt were not well drawn, some were too drastic. He was aware of the difficulties of any sudden or complete conversion of systems and once declared that the Bureau "never advised or favored the introduction of any bill making the metric system compulsory for all purposes." It was the Bureau's position that it was "desirable to work toward a decimal and international system of weights and measures * * * [and] gradually extend the metric system into common work." [129]

The qualification was ignored by critics of the Bureau, who saw any effort on behalf of the metric system as a threat to all domestic tranquility. It was indictment enough that "the Bureau of Standards under the administration of Dr. Stratton has been the seat of metric propaganda for many years. The doctor himself is known as a hobbyist, not to say lobbyist, for the metric system." [130]

Upon the entry of the United States into the war, committing our armies in France to the metric system, hope rose that metric legislation might finally be passed. War fervor and the AEF requirement were believed to have weakened the resolve of many former objectors. New industries, like munitions and aeronautics, and older ones, like the electrical industry, were working with the metric system in supplying the Allies and other nations

[127] Hearings on H.R. 2054 * * * before the Committee on Coinage, Weights, and Measures, Feb. 6–Mar. 6, 1902, pp. 151–165 (L/C: QC91.U48).

[128] Kelvin's testimony appeared in supplementary hearings before the Committee on Coinage, Weights, and Measures, Aug. 24, 1902 (L/C: QC91.U481); Bell's appears in his article, "Our heterogeneous system of weights and measures," National Geographic, 17, 158 (1906).

[129] Letter, SWS to editor, American Industries, Aug. 10, 1920 (NBS Box 20, MS). Dr. Burgess reaffirmed this position on the metric system in NBS Annual Report 1923, pp. 25–27. Stratton was confident, as he told Congress, that American industry would sooner or later "have to come to it" because of foreign trade. He "always felt that the request [for general use] should come from the public [and not be initiated in Congress], and that the public should be educated more into the system before it was introduced." Hearings * * * 1921 (Jan. 2, 1920), p. 1594.

[130] Letter, Samuel Russell to Secretary of Commerce Hoover, Apr. 8, 1921 (NBS Box 20, MS). Hoover replied (Apr. 23, 1921) that he was "inclined to favor the metric system as the only possible substitute for our present system."

abroad, and Stratton predicted with confidence that it would be in common use "in a comparatively short time." [131] He was not a good prophet.

In support of the first metric bill presented after the war, General Pershing himself attempted to set at rest public fears by reporting that the troops overseas "were able readily to change from our existing system of weights and measures to the metric system." He urged its adoption "to the greatest extent possible * * * [as] the only system with a purely scientific basis." [132] Again the measure failed. Said a disappointed Stratton, "The opponents of the metric system see to it that every Congressman is reached, and Congress does not see that it originates practically from a single source." [133] Almost certainly he referred to the American Institute of Weights and Measures, founded in 1917 by the antimetricists Samuel Dale and Frederick A. Halsey. With the support of the National Association of Manufacturers and less than a dozen other trade organizations, Dale had founded the institute for the sole purpose of opposing metric legislation—and had succeeded.[134]

Another metric proposal followed a year later, but the era of normalcy was at hand and Stratton had to admit that the political climate was no longer favorable. Moreover, past experience had shown that neither inducing prominent personalities to appear before Congress, soliciting petitions, nor lending the Bureau's own prestige were sufficient. More was needed. The Bureau must adopt a policy of wider education and secure the conversion of members of Congress through their constituents.

Between 1920 and 1930, 23 metric bills were introduced in Congress. Science in industry and industry itself, with an eye on foreign trade, inclined more and more to the metric system.[135] But the great depression saw foreign

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[131] Remarks of SWS reported in minutes of meeting, Standards Committee, Society of Automotive Engineers, Feb. 16, 1917, pp. 3–4, 20 (NBS Box 20, MS).

[132] Letter, John J. Pershing to W. Mortimer Crocker, Nov. 24, 1919, transmitted to SWS (NBS Box 20, MS).

[133] Confidential letter, SWS to Fred R. Drake, Drake & Co., Easton, Pa., Dec. 29, 1920 (NBS Box 20, MS).

[134] See miscellaneous documents of the A.I.W.M. in L/C: QC81.A347 and A349. The counterpart of the American Institute is the British Weights and Measures Association, active since its founding in 1904 in opposing introduction of the metric system "as a British standard."

[135] NBS C593, "The Federal basis for weights and measures" (R. W. Smith, 1958), p. 19.

How "vital and timely" the subject seemed just after World War I is evident in the special report prepared by the National Industrial Conference Board, The Metric versus the English System of Weights and Measures, Research Report No. 42 (New York: Century, 1921).

In support of a metric bill introduced in 1921, Stratton reported 102,842 petitions received at the Bureau, 15,501 of them from engineers and manufacturers, and 98.87 percent of the total number favorable (memo, SWS for Secretary of Commerce Hoover, Oct. 29, 1921, NBS Box 20, MS).

trade fall away and a growing sense of isolation fill the Nation. In the decades after, interest in the metric system was revived periodically but the tide of congressional and public sentiment remained against conversion.

"THE LEGACY LEFT TO US"

On this side of the Atlantic it seemed that the war ended as abruptly as it began. Newspaper accounts of the fighting in France all through October 1918 indicated no weakness in the German armies anywhere. After the first week of the Meuse-Argonne battle, AEF advances were measured in meters as, under simultaneous pressure from the French and British to the west and north, the German armies gave ground slowly. Military intelligence reported that they were probably withdrawing to their prepared Meuse-Antwerp line, where they would hold through the winter.

Pershing's plans for a renewal of his offensive in the spring of 1919, with victory that summer, were summarily shelved upon the sudden political collapse of Germany in early November. Here at home, industry, finally coming into full-scale production after a year's preparation, awoke to find the war over. Production lines stopped, contracts were canceled, and all war emergency measures suddenly came to an end.

On November 20, 9 days after the armistice, Secretary of Commerce Redfield wrote Stratton asking him what activities of the Bureau would be discontinued as military and naval operations ceased, and what reduction in force might be expected as a result. Neither discontinuance nor reduction was contemplated, Stratton replied. On the contrary, as a result of the wartime experience, he expected greater demands than ever to be made on the Bureau by the military services, both for specifications and increased standardization of their purchases and for the development of new devices and materials. "One of the great lessons taught by the war," said Stratton, "is the need for engineering and scientific work in connection with our defenses." Such research must never again be left until we were at war. Furthermore, the development of substitute materials and the rise of new industries called for expanded Bureau assistance: "There was never a time when the need for industrial research was greater than the present." And he asked Secretary Redfield for help in persuading Congress to lend assistance both to the military and civil departments of the Government and to industry for this research.[136]

Dr. Burgess, concerned with the fact that War Department funds for research automatically terminated within 6 months of the end of hostilities, proposed further action by the Director:

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[136] Letter, Redfield to SWS, Nov. 20, 1918, and reply, Nov. 30 (NBS Box 2, AG).

> With the curtailment of military appropriations to the Bureau by Congress, it becomes necessary for the military bureaus to provide funds for the investigations in which they are interested.

He asked Stratton to seek special funds from Navy Ordnance to continue the Bureau investigation of light armor plate steels and Army Ordnance funds to continue the study of machine gun corrosion.[137] A score of other investigations would need similar financing.

The Bureau thus sought help through a wartime measure, the Overman Act, passed by Congress on May 20, 1918.[138] In the interest of economy and greater efficiency, the act authorized, among other things, the transfer of funds from one Government agency to another, where an agency with funds but lacking the staff or facilities for an investigation, survey, or other service that it required, might turn the necessary funds over to the investigating agency. Under the act the military services had transferred well over half a million dollars to the Bureau in 1917 and 1918 (apart from military funds directly appropriated by Congress to the Bureau), to carry out wartime research for them.

The device of interagency fund transfers, although never officially sanctioned before the Overman Act, had prevailed for a number of years among Government agencies. Stratton had not approved of it. Seeking additional funds from Congress at a hearing in 1910, he rejected a suggestion that he avail himself of this custom, insisting that the Bureau "should not be under obligation to any individual or any department when it undertakes testing." [139]

Now suddenly the Bureau was alarmed. It had a plant more than twice its prewar size. The end of hostilities left it stranded with many investigations for the services far from completed. Particularly important, the Bureau felt, was its research on radio vacuum tubes and coil aerials for the Signal Corps, its testing of rubber compositions and tires for the Motor Transport Service, structural materials testing for the Navy Bureau of Yards and Docks, and the work on airplane fabrics and aviation engines. Upon strong pleas by Stratton, President Wilson on March 4, 1919, authorized the transfer of $100,000 from unobligated funds of the Quartermaster Corps to the Bureau to complete some of these investigations.[140]

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[137] Memo, Burgess for SWS, Nov. 25, 1918 (NBS Box 5, FPG).

[138] For passage of the Overman Act, possibly the most important piece of legislation enacted for the prosecution of the war, see Paxson, American Democracy and the World War, II, 225–226.

[139] Hearings * * * 1912 (Dec. 2, 1910), p. 273.

[140] Letter, Secretary of War to Secretary of the Treasury, Mar. 4, 1919; letter, Secretary of Commerce to Secretary of War, Apr. 10, 1919, and attached corrrespondence (NBS Box 5, FPG). Further correspondence on tranferred funds appears in NBS Box 7, ICG 1918–22.

As appropriations to the military plummeted after the war, the Bureau's transferred funds fell to $62,000 in 1921 and $3,000 in 1922.[141] But the precedent for transferred funds had been established and with no alternative Stratton accepted it. "We would rather handle [all research] * * * as far as possible, on our regular funds," he told the House Appropriations Subcommittee, "but I see no objection [under the circumstances]. * * * I believe it would be a good thing." A paragraph on transferred funds that Stratton prepared and read to the committee was, with minor changes, accepted for inclusion in the Bureau budget. Appearing in the appropriation act of May 20, 1920, and repeated annually thereafter, it stated that—

> the head of any department or independent establishment of the government having funds available for scientific investigations and requiring cooperative work by the Bureau of Standards on scientific investigations within the scope of the functions of that Bureau and which it is unable to perform within the limits of its appropriations, may, with the approval of the Secretary of Commerce, transfer to the Bureau of Standards such sums as may be necessary to carry on such investigations.[142]

Dr. Stratton's successors were often to find it easier to interest other Government agencies in supporting research at the Bureau than to obtain increased funds from Congress.[143] Not Stratton, whose Bureau could not wait for proffered funds. At the second postwar hearing before the House Subcommittee on Appropriations, he requested what one of his auditors protested as "practically double the appropriation asked for last year." It was over a million dollars, Stratton admitted, but actually represented only a 60 percent increase. Item by item he explained his needs, and most of the request was granted.[144] The appropriation bore witness not only to the powers of Stratton's persuasion but to the esteem the Bureau had won for itself in Congress.

By far the largest item in the new Bureau budget was for industrial

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[141] These sums apparently represent direct transfers of funds for other departments. The blow was softened, however, by the transfer of additional departmental funds through congressional action in 1921, 1922, and 1923, and are included with special appropriations to the Bureau. See app. F and NBS Annual Reports for those years.

[142] Hearings * * * 1921 (Jan. 2, 1920), p. 1598. The provision as enacted in 41 Stat. 683, is cited in Weber, The Bureau of Standards, p. 73. See also letter GKB to Air Service, WD, June 22, 1923 (NBS Box 41, FPG).

[143] Transferred funds to the Bureau rose from $60,870 in 1923 to approximately $418,600 in 1930, or almost 15 percent of total funds. They maintained the 1930 level until World War II. After World War II, transferred funds at times constituted as much as 85 percent of total Bureau working funds.

[144] Hearings * * * 1921 (Jan. 2, 1920), p. 1525.

research, unconnected, as it had been earlier, with Government testing. Back of Stratton's arguments for this research was the realization, crystallized by the wartime experience, that the recent alliance of science and industry was certain to continue in the postwar years. Nor had it escaped notice that most of the wartime triumphs in physics and chemistry were of European origin. In the coming years the great industrial organizations of this country must, to remain competitive, increase their research activities, and in doing so would make unparalleled demands upon the Nation's scientific resources.

Foreseeing this, in 1918 the National Research Council and the Rockefeller Foundation had raised the question of establishing a permanent research institution devoted to pure research, to which industry after the war might look for leadership in the physical sciences. "Is the Federal Government," George E. Vincent, president of the Rockefeller Institute, wrote to Robert A. Millikan of the Council, "in a position to create a separate institution on the analogy of certain research units in the Department of Agriculture and in the Geological Survey? Is the Bureau of Standards capable of extension into a national research institution?"[145] The questions remained, but hope of implementing them ended with the armistice as Congress turned its back on war and all its prerogatives and the wartime organization of science and scientists melted away.

Although Stratton, as an executive member of the National Research Council, certainly knew of the questions under consideration, no correspondence has been found to indicate what part, if any, the Bureau took in them. Quite apart from the interest they must have aroused, it is more than likely that Stratton had already determined on the postwar course of the Bureau. As nothing else could have, the war opened to the Bureau new vistas of its role in the Nation's commerce and industry. When first called on to meet the Nation's war needs, industry had shown itself both fearful and resentful of Government interference.[146] Within months, as the magnitude of the task stood revealed, industry came to realize that only the Federal Government could mobilize and marshal the Nation's resources and command the scientific assistance that industry must have to produce the materials of war. And it discovered in the Bureau not only technical assistance and

[145] Letter of Feb. 5, 1918, quoted in The Autobiography of Robert A. Millikan, pp. 180–181. See also Dupree, Science in the Federal Government, pp. 323–325.

[146] Clarkson in Industrial America in the World War (pp. 318, 427, 449), speaking of the early efforts of the War Industries Board to harness industry to the war needs of the country, said the Board repeatedly found that "business and patriotism were confined to separate compartments." Besides industry's foot-dragging in meeting specifications, Government war purchases for a time were attended by "a saturnalia of high prices."

necessary measurements but a source of the scientific principles upon which its operations must depend.[147]

The Bureau itself realized for the first time what could be done when its 2- and 3-man sections became 50-man sections and were supported with adequate funds and equipment. It was no more than a glimpse, for Bureau accomplishments, by comparison with the tasks laid before it, seemed few. There had hardly been time to state the problem, acquire the equipment, or find the staff before the armistice came. But it was a turning point in the outlook of the Bureau. If it could not be the hoped for center for pure research, the Bureau would undertake the applied research for industry that industry could not do for itself.

As Stratton and Secretary Redfield told the House subcommittee late in 1918, "Practically all of the military work [conducted by the Bureau] has an industrial value," and that research must be continued and expanded on behalf of industry.[148] Other nations realized the extraordinary role science in industry had played in the conflict, and as a result Canada, Japan, and Australia were already planning national laboratories to look after their industrial development. In beating swords into plowshares, Stratton told Congress, the Bureau must continue its research on airplane engines and instruments and take up much needed studies of automotive engines as well. The study of problems raised by the war in optics and optical instruments, in radio, and in acoustics had only begun.[149]

Much of the proposed peacetime research that Stratton and Redfield outlined to Congress was to be carried on, the latter said, in "the legacy left to us," the Bureau's great Industrial building, clearly destined to become "the center and home of the scientific studies of the Government for the

[147] A historian-scientist in the glass industry was to say twice within 20 pages of that period: "Much of [the subsequent] increase in knowledge was the direct product of the enforced extension of the optical glass industry during the war. [There was] * * * an awakened realization by the glass industry * * * that the soundest foundation for a strong industry is the understanding of its fundamental scientific principles." George W. Morey, The Properties of Glass, pp. 5, 26.

[148] Hearings * * * 1920 (Dec. 12, 1918), p. 958. A year later Stratton noted that the Bureau "has gotten practically 100 percent salvage value out of all of its scientific research for the War Department." Hearings * * * 1921 (Jan. 2, 1920), p. 1531.

The new emphasis on research for industry and standardization in industrial production, manufacturing, and distribution were subjects of many articles shortly after the war, among them G. K. Burgess, "Science and the after-war period," Sci. Mo. 8, 97 (1919); E. B. Rosa, "The Bureau of Standards and industrial standardization," Am. Federationist, 25, 1029 (1919); "Work of the Bureau of Standards during 1918," Science, 49, 39 (1919)); P. G. Agnew, "The work of the Bureau of Standards," Ann. Am. Acad. Polit. Soc. Sci. 82, 278 (1919); "The Bureau of Standards and the war," Nature, 103, 197 (1919); C. H. Claudy, "Science in the war," Sci. Am. 120, 653 (1919).

[149] Hearings * * * 1920 (Dec. 12, 1918), p. 957.

benefit of the industries of the country." [150] There the Bureau would continue to foster the new industries born of the war, the manufacture of scientific instruments, of aeronautical instruments, of automotive power plants, and the science of electrodeposition. Redfield pointed to three others that had grown out of recent Bureau investigations: The making of chemical porcelain, never before produced in this country; the making of hard-fired porcelain, for which we had been wholly dependent on Germany, Austria, and Great Britain; and the making of pyrometer tubes, polarimeters and other scientific instruments, previously obtained from Germany. In applying science to industry, declared Redfield, "We have begun to do the thing that Germany did 35 years ago." [151]

Still other industries in which research had just begun included the making of precision gages, dyes and chemicals, petroleum products, the rare sugars, the platinum metals, rubber, paper, leather, and ceramics.[152] The fields of metallurgy, photographic technology, and construction and building materials must be examined anew. And Redfield promised that "we will put in [the Industrial building] a small woolen mill, a cotton mill, etc.," to investigate some of the basic problems in cloth manufacture that engaged so much effort during the war and found little solution.[153]

But the real legacy left to the Bureau was not a building or a program but a series of intangibles: the closer relation that had arisen between the Bureau and industry; the beginning of recognition of what scientific methods could contribute to industrial technology; and perhaps more important, the realization by industry that fundamental science, which seemingly produced nothing, might have far-reaching consequences at some future time. Industries that had set up their own laboratories before the war doubled and

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[150] Ibid., p. 958.

[151] Ibid., pp. 932–933, 940. Redfield's remark is quoted in letter, Elizabeth Minor King, "New York Evening Post," to Redfield, Mar. 22, 1919 (NARG 40, Box 119, file 67009/63).

[152] In a memorandum to the Bureau of Foreign and Domestic Commerce, Dec. 16, 1918, Stratton listed as new things produced on a commercial scale since 1915, in many instances with Bureau help: manganin, a special alloy for use in electrical work; high-grade volumetric glass apparatus; high-grade optical glass; four types of photographic dyes; fused quartz of optical quality; chemical glassware (Pyrex); oxygen control apparatus; improved design in aeronautical instruments; burned shale aggregates for concrete ships; cotton airplane fabric; photographic paper; cigarette paper; and fine grades of artifical abrasives (NBS Box 10, IG).

[153] Hearings * * * 1920 (Dec. 12, 1918), p. 958. Acquired in 1918, the wool and cotton mills were moved into the Industrial building upon its completion early in 1920. See letter, Textile Research Co., Boston, Mass., to SWS, June 7, 1919, and attached correspondence (NBS Box 4, AP). The woolen mill was never set up. Realizing its need for scientific assistance, the textile industry, working in close cooperation with the Department of Agriculture and the Bureau, organized its own research laboratories in the 1920's. About 1930 the cotton mill, no longer necessary, was dismantled. Conversation with William D. Appel, Mar. 4, 1963.

tripled their scientific staffs, and others that had formerly considered research an expensive frill now made room for the scientists and engineers they began to enlist.[154]

For the Bureau's industrial research, Stratton asked a special congressional appropriation of $363,000, half again as much as the combined sums requested for its previous largest programs, structural materials testing and the testing of Government materials. In addition, he asked for more than four times the past year's appropriation for public utility investigations. The war had put enormous pressure on the utilities, dramatizing, he said, their "engineering and economic problems." Not only gas and electric companies, but telephone and telegraph companies had been overtaxed by the service demands of the war industries, war workers, and military camps. Hardest hit, the telephone company in the District of Columbia had been forced to file a petition for both traffic and financial relief.[155] "The public utilities of the country are trembling in the balance," Redfield told Congress, and if the Bureau did not undertake the necessary research to provide practical standards and scientific data on their behalf, then each of the 48 States would have to establish separate laboratories to do this work.[156] Congress agreed that it was a Bureau responsibility.

For a peacetime America, it was an immense and expensive program the Bureau projected. With the increase in staff, statutory salaries for Bureau test and research personnel had gone up from less than $300,000 in 1916 to nearly $500,000 for fiscal year 1920. In the same period, special appropriations, which included salaries for the additional staff, rose from $300,000 (for 9 projects) to $1,310,000 (for 25 projects). Of the projects under special appropriations, four alone—industrial research, public utilities, structural materials, and testing of Government materials—accounted for well over half the total of special appropriations and more than one-third of total Bureau income. Convinced of the peacetime worth of these investigations begun with public or military funds during the war, Congress made cuts in some but voted to continue them all. Their benefit to industry was beyond question.

A year after Vincent and Millikan raised the question of extending the functions of the Bureau of Standards on behalf of industry, Dr. Stratton, in the introduction to his annual report for 1918-19, accepted the challenge in a significant restatement of Bureau policy. The relation of the Bureau's work to the public, to the Government and to science remained unchanged,

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[154] Where in 1920 there had been 300 industrial research laboratories in this country, a decade later there were 1,625, staffed by more than 34,000 people. Dupree, Science in the Federal Government, p. 337.

[155] "War Work," pp. 274-276.

[156] Hearings * * * 1920 (Dec. 12, 1918), p. 941; NBS Annual Report 1918, pp. 52-53.

but henceforth the Bureau declared itself "fundamentally concerned, either directly or indirectly, with the improvement of methods of production or the quality of the output" of industry. It thus occupied "somewhat the same position with respect to the manufacturing interests of this country that the bureaus of the Department of Agriculture do to the agriculture interests." [157] Such was the intention of the Bureau when, with the incoming Harding administration, Herbert Hoover became the new Secretary of Commerce.

[157] NBS Annual Report 1919, p. 21.

The Exchecquer standard wine gallon of Queen Anne, 1707.

The Physikalisch-Technische Reichsanstalt at Charlottenburg, Germany. It was, said Dr. Rosa after a visit there, "an illustrious example of how much can be accomplished where research and testing are combined in one institution." (*MS speech in NBS Box 22, PRA 1901–03.*)